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REGIONAL AIR POLLUTION STUDY: A PROSPECTUS

Part III — Research Facility

Prepared for:

THE ENVIRONMENTAL PROTECTION AGENCY
NATIONAL ENVIRONMENTAL RESEARCH CENTER
RESEARCH TRIANGLE PARK, NORTH CAROLINA

CONTRACT 68-02-0207

SRI Project 1365

STANFORD RESEARCH INSTITUTE
Menlo Park, California 94025 · U.S.A.

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SRI Project 1365

R. T. H. COLLIS, *Director*
Atmospheric Sciences Laboratory (Project Director)

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Office of Research Operations

FOREWORD

This Prospectus was prepared by Stanford Research Institute for the Environmental Protection Agency under Contract No. 68-02-0207. While this Prospectus has been reviewed by the Environmental Protection Agency and approved for publication, approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor is it intended to describe the Agency's program.

The complete Prospectus for the Regional Air Pollution Study is presented in four parts.

Part I	Summary
Part II	Research Plan
Part III	Research Facility
Part IV	Management Plan

A table of contents for all parts is provided in each of the four parts to facilitate the use of the Prospectus.

ACKNOWLEDGMENT

This Prospectus was prepared at the Institute by a project team representing the full range of disciplines necessary for the comprehensive analysis of problems of air pollution. Research team members were drawn from four of the eight Institute Research Divisions, including the following:

Electronic and Radio Sciences
Physical Sciences
Information Science and Engineering
Engineering Systems

Because of the interdisciplinary nature of the effort, the contributions and research findings of many team members are distributed throughout this Prospectus rather than concentrated in one or more specific chapters. Accordingly, contributions are acknowledged below by general areas associated with the study of air pollution problems.

This Prospectus was prepared under the supervision of R.T.H. Collis, Project Director. The Project Leader was Elmer Robinson (now of Washington State University) until 15 January, when Richard B. Bothun, who had been Deputy Project Leader, succeeded him.

The main contributions were as follows:

- Elmer Robinson--Project leadership and the formulation of the Research Plan

- Richard B. Bothun--Project leadership and administrative management and the formulation of the Management Plan.

Technically, the principal contributions were:

- Richard B. Bothun--Management, scheduling, costing, planning

- Leonard A. Cavanagh--Air quality instruments, atmospheric chemistry

- Ronald T. H. Collis--Meteorology, remote sensing, research planning
- Walter F. Dabberdt--Transport and diffusion modeling, meteorology, instrumentation
- Paul A. Davis--Solar radiation, tracer studies
- Roy M. Endlich--Meteorological models, satellite systems
- James L. Mackin--Helicopter and aircraft systems
- Elmer Robinson--Meteorology, instrumentation, atmospheric chemistry, research planning
- Sylvin Rubin--Data processing systems
- Konrad T. Semrau--Source inventory and emissions
- Elmer B. Shapiro--Communication systems
- James H. Smith--Atmospheric chemical transformation processes
- Eldon J. Wiegman--Synoptic climatology

Valuable contributions were made in the latter stages of the project by Dr. W. A. Perkins and Mr. J. S. Sandberg, consultants.

The Institute wishes to express its appreciation for the assistance and provision of information by many staff members of the Environmental Protection Agency, especially Charles R. Hosler, Contracting Officer's Technical Representative; Dr. Warren B. Johnson, Jr., Chief, Model Development Branch; Robert A. McCormick, Director, Division of Meteorology; and Dr. A. P. Altshuller, Director, Division of Chemistry and Physics.

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Chapter IX

INTRODUCTION TO FACILITY DESIGN AND OPERATIONS

Part III of this Prospectus includes the conceptual definition and detailed discussion of the permanent instrument, data-handling, and processing facility planned for the Regional Study. The facility, by its design and mode of operation, is intended to provide the basic support to the research efforts defined within the Research Plan presented in Part II of this Prospectus. The facility capability, however, is expected to be augmented for several of the research experiments requiring unique or specialized instruments and other equipment. Such additional required instruments and equipment or personnel are considered as an integral part of the experimental effort rather than of the St. Louis facility itself. The facility as defined in Part III was used to prepare the estimates covering schedules, staffing, and costs presented in Part IV of this Prospectus.

Early in the course of preparing this Prospectus, consideration was given to the possible locations in the nation that would be suitable as the site for the Regional Study. Four alternative sites were recommended, and the St. Louis urbanized area and rural environs was selected as the most appropriate by the EPA.

The St. Louis facility is conceived ~~in this Prospectus~~ as consisting of a system of air quality and meteorological instrument stations established within an area roughly enclosed by a circle of 100-km radius with the St. Louis arch as its center. A central support facility is also planned, which includes data-handling and processing equipment, office and laboratory space, and repair and maintenance shops. Most instrument stations are expected to be linked to the central facility by telephone circuits to permit automated remote data recording at the central facility.

The St. Louis facility is planned as the basic instrument system of the Regional Study. It could be operated in a fully continuous or part-time mode to develop a comprehensive data base of air quality and meteorological conditions. Detailed statistical and other analyses could then be performed as required by the various elements of the Research Plan. During the various field studies and data-acquisition efforts covered in the Research Plan, the facility would be operated to support these efforts most effectively. Support could include equipping the instrument stations with additional instruments, locating transportable stations as specified by the research group, preparation and operation of specialized data processing programs, instrument and experimental technician support, and other activities.

Six types or classes of instrument stations are included in the facility. These range from the permanently installed Class A_1 stations with 30-meter instrument towers equipped with a full complement of air quality and meteorological instruments to the trailer-mounted Class C_2 stations having no air quality instruments and a single meteorological instrument. The principal characteristics of the stations are summarized in Table IX-1.

Stations of Classes A_1, A_2, and B_1 are visualized as permanently sited throughout the Regional Study, although this is certainly not a fixed requirement. These stations are considered the basic units for the long-term observational program. The Class B_2 stations have the same instrument complement as the Class B_1 stations, but they are transportable units housed in trailers. The Class C_1 stations are denoted as transportable units since a trailer is used for instrument installation. The fact that the station is equipped with a 30-meter tower, however, suggests less frequent movement than the other transportable stations.

The Class C_2 stations are a hybrid unit. As part of the central facility they include the trailer unit, tower, and digital data terminal equipment. They will be used by the various groups carrying out field experiments and data-gathering efforts associated with the various research efforts presented in Part II of this Prospectus. Any additional instrumentation required at a Class C_2 station in support of these field efforts would be considered a part of the particular research effort rather than of the St. Louis facility. Accordingly, the instrumentation of the Class C_2 stations would be expected to vary widely over the course of the Regional Study. This same concept would also apply to instruments added to other classes of stations set up in the support of field activities.

Data acquisition and handling in the St. Louis facility is expected to be automated to the greatest possible extent. Instrument observations at all but the Class C_1 and C_2 stations are planned to be transmitted by telephone circuits to the central facility for automatic computer-controlled recording. The Class C_1 and C_2 stations are currently planned to have local data-recording facilities, but further analysis might indeed indicate these too could efficiently utilize a remote reporting capability.

Table IX-1

CLASSIFICATION OF THE REGIONAL STUDY INSTRUMENT STATIONS

	Class of Station					
	A_1	A_2	B_1	B_2	C_1	C_2
	Number of Instruments					
Air quality instruments						
Carbon monoxide - methane - hydrocarbon	1	1	1	1	--	--
Hydrogen sulfide-sulfur dioxide	1	1	1	1	--	--
Total sulfur	1	1	--	--	--	--
Ozone	1	1	1	1	--	--
Nitrous oxide - oxides of nitrogen	1	1	1	1	--	--
Nephelometer	1	1	1	1	--	--
Carbon monoxide (NDIR)	1	1	--	--	--	--
Hi-vol sampler	2	2	2	2	--	--
Meteorological instruments						
Temperature	1	1	--	--	1	--
Wind direction and speed	3	3	1	1	3	1
Pyranometer	1	--	--	--	1	--
Pressure transducer	1	--	--	--	1	--
Mercury barometer	1	--	--	--	1	--
Net radiometer	1	--	--	--	1	--
Dew point hygrometer	1	--	--	--	1	--
Rain - snow gauge	1	--	--	--	1	--
	Station Characteristics					
Tower height						
30-meter	x	x			x	
10-meter			x	x		x
Data recording						
Remote	x	x	x	x		
Local					x	x
Mobility						
Fixed	x	x	x			
Transportable				x	x	x
Total quantities	9	8	24	8	4	24

The digital data terminal equipment of the remotely reporting instrument stations interrogates each air quality and meteorological instrument at a predetermined frequency, converts the analog instrument output to its digital equivalent, and stores the digital data in a relatively small-capacity magnetic core memory. Upon command from the central facility, expected to occur at approximately 15-minute intervals for each station, the stored data are automatically transmitted to the central facility. Calibration curves of all instruments are stored in the data-processing system at the central facility, so that immediate conversion is made from the digital data format to engineering units for archiving.

Each air quality and meteorological instrument would be equipped with a solid state nonerasable memory unit to serve as an identifier of each instrument. A unique serial number, or equivalent, of each instrument would be coded into the identifier with the identifier then mounted on the instrument. At each interrogation of each instrument, the identifier would respond immediately before or after the instrument reading was acquired, so that the instrument reading and its identification would always be together. This procedure should result in an absolute minimum of data ambiguity and erroneous interpretation and is judged to be far superior to customary procedures employing instrument log books and other manual methods.

The principal data-handling and processing function at the central facility would include the recording and archiving of all instrument station data and other field and experiment information. The archival tapes would be forwarded to the Research Triangle Park or other EPA installations, as appropriate, or to contractors for use in their analyses on a particular research project. Minimal detailed data analysis is expected to be carried out at the St. Louis facility, and the electronic data-processing equipment is sized accordingly. Selected research experiments may require limited data processing during their execution, and the St. Louis facility should have the required capability. But, large scale data processing covering data acquired over a period of, say, the spring and summer seasons would be expected to be undertaken on the larger computer systems existing at the Research Triangle Park and elsewhere.

The instrument stations comprising the St. Louis facility are planned to be located within a circle of approximately 100-km radius centered generally on the St. Louis arch. Eight Class A stations are symmetrically located around the 100-km circle, while an additional eight are symmetrically deployed on a 40-km square with the arch as its center. The final Class A station is planned at the arch itself. Depending upon actual conditions at the arch site, advantage might well be taken of nearby taller television or other towers.

The Class B_1 stations are planned for installation on a uniform square grid about the arch with station spacings of approximately 12 km.

The remaining stations are considered to be transportable and would be deployed as required to support a given field data-acquisition program. This is particularly true for the Class C_2 stations. The stations other than the Class C_2 would generally be expected to provide the overall or ambient observations of air quality, meteorological, and other parameters of interest on an area-wide basis. Observations in detail within a specific smaller area would be carried out by deployment of the Class C_2 stations within the area of interest.

The precise station locations will, of course, depend upon the availability of suitable sites, so that the pattern presented here must be regarded as tentative. Instrument station sites must be selected with respect to several important factors, including freedom from unique or overriding micrometeorological effects, general absence of nearby significant pollutant sources, convenient access to electric power and communication utility services, and free access at all times. Only a detailed field survey will reveal sites possessing these and other necessary characteristics.

[illegible]

The St. Louis ground-based instrument system is expected to be augmented by an aerial observational capability. Aerial measurements are expected to be made on both a routine basis and in support of special research experiments using aircraft and the proposed METRAC system. The existing EPA aerial observation capability has been examined along with alternative methods. Significant advancement in the state of the art of aerial measurement is expected during the course of the Regional Study, so that planning of the aerial support program should be flexible.

Chapter X

ST. LOUIS SITE SELECTION

Summary

The preparation of the Regional Study Prospectus depended in part upon the actual area of the nation in which the Regional Study would be carried out. Accordingly, an early task entailed the development of site selection criteria and the evaluation of the larger urbanized areas of the nation with respect to their conformance to the criteria. Because of the ready availability of statistical data, the Standard Metropolitan Statistical Areas (SMSAs) were used as the basis for analysis. The evaluation resulted in the nomination of four candidate sites. These were:

Birmingham, Alabama
Cincinnati, Ohio
Pittsburgh, Pennsylvania
St. Louis, Missouri, including the Illinois portion.

These candidate sites and the data supporting their nomination were submitted to the EPA for consideration. St. Louis was selected as the Regional Study site by the Assistant Administrator for Research and Monitoring. The rating of the four sites for each criterion is provided in the following tabulation.

Criterion	Birmingham	Cincinnati	Pittsburgh	St. Louis
Surrounding area	Fair	Poor	Good	Good
Heterogeneous emissions	Fair	Fair	Fair	Good
Area size	Good	Good	Good	Good
Control program	Poor	Good	Good	Good
Information	Poor	Good	Fair	Good
Climate	Good	Fair	Fair	Good

Birmingham compares reasonably well with most of the more important criteria but in general it is lowest overall. The bulk of the surrounding area is essentially rural, although not heavily agricultural, and the nearest candidate SMSA is approximately 140 miles away. Interarea pollution would tend to be small. The area has a fair degree of heterogeneous emissions but is strongly dominated by the steel industry. The area has no petroleum refineries and only a small representation of the chemical industry, chiefly agricultural fertilizers. No power plants are within the urban area. Space heating is largely by natural gas, but this tends to be true for all areas. Observed atmospheric concentrations of suspended particles are quite high, but SO_2 concentrations are low. The Birmingham area is moderate in size, so that the instrumentation and other facilities necessary for the Regional Study ought not be excessive. The pollution control program in the Birmingham area is so poorly defined as to make the area attractive perhaps for the Regional Study. This advantage would derive from the chance to follow the changes in the area as control programs were initiated and sources were brought into compliance. However, only minimal historical information is available and the Regional Study would be faced with the task of developing a complete set of required information. Climatically, Birmingham would be a good site. The area is sufficiently northerly to have the continental-type climate representative of a large section of the nation but, at the same time, its southerly location would permit virtually year-round experimental efforts. The surrounding area is forested hills with not much area used for farming. On a scale of 1 to 3 for "poor" through "good," Birmingham scales 12 out of a possible 18.

Cincinnati is rated as poor with regard to the surrounding area. The SMSA is contiguous with two other SMSAs and the central city is separated from Dayton--a candidate region--by about 40 miles. Rural fringes may be smaller than those in other areas and interarea pollution is a greater possibility. The heterogeneity of emissions is fair. The area has some ferrous and nonferrous metal industry and small levels of the primary chemical and petroleum refining industries. The Cincinnati area size is rated as good but the influence of Dayton and other SMSAs in the area must be considered. The pollution control program in the area has been in existence for some time and has shown considerable effectiveness, so that the area is ranked as good in this regard. The available historical information is appreciable; the programs conducted at the Taft Center and in Cincinnati when the federal air pollution program was centered there would be especially valuable in providing important historical information. Finally, the climate in the area is representative of the continental type and should permit experimental efforts throughout most of the year. Overall, Cincinnati scales 14 on this final list.

Pittsburgh appears overall to be a generally suitable area. Even though the SMSA is contiguous with two others, they are relatively small and should not cause significant interarea pollution. The nearest candidate SMSA--Youngstown-Warren--lies over 100 miles to the northwest, providing a reasonable degree of isolation. Appropriate rural areas appear to be in relative abundance. The area has a fair heterogeneity of emission sources, although dominated by the steel industry. The area does have some industrial activity in chemicals, petroleum refining, and nonferrous metals. The size of the Pittsburgh area would not appear to strain the resources expected to be available in the Regional Study. Pollution control programs have been in existence for an appreciable period and have had marked effect. However, the current pollution levels are high enough that the continuing abatement and control program should provide important data for the Regional Study. Historical data are regarded as fair, studies of various types having been conducted since 1960 usually on a county or city basis within the SMSA. Climatically, Pittsburgh is rated as fair. Winters in the area are sometimes severe and may restrict year-round experimental activities. More importantly, however, Pittsburgh lies in a distinct river valley which tends to make it less than ideally representative of many areas and perhaps not immediately applicable for many generalized air quality models. On an overall basis, Pittsburgh earns a scale value of 15.

St. Louis is rated as good with respect to all points. The nearest candidate SMSA is 250 miles distant, giving St. Louis the highest measure of isolation of the four considered here. The rural fringe should be extensive. The heterogeneity of emissions is appreciable, probably greater than that of any other candidate area. The area has large facilities for steel production, oil refining, and primary chemical production; significant facilities are also found for nonferrous metal production and agricultural fertilizers. The area size is considered as good but likely represents the upper limit. The air pollution control program of St. Louis is one of the oldest in the nation, and it has been relatively effective. Observations of the effectiveness of abatement and control measures during the course of the Regional Study may be therefore more difficult to obtain than in other candidate areas. However, since the St. Louis area was relatively highly polluted at the initiation of the program and still seems to exceed air quality criteria, effectiveness measures still might be readily developed. The available historical information for St. Louis is probably more plentiful than that for any other candidate area. Representative of these data is the large multiagency eight-volume study of the St. Louis area published in 1967 by the Public Health Service under the title "Interstate Air Pollution Study." Reports of this type, plus the 20-year air pollution control program, provide impressive data. Additionally, at least three studies of the St. Louis area are currently under way that will add to the available information. Finally, the St. Louis area climate tends to be representative of many candidate areas and also permits virtually year-round experimental activity. The scale value for St. Louis is 17.

Site Selection Criteria

The extent to which the objectives and goals of the Regional Study can be achieved may indeed depend in an important way upon the region selected for the experimental effort. Accordingly, the objectives and goals of the Regional Study should stand as first-order constraints on the development of selection criteria for the region followed by second-order constraints resulting from numerous factors such as required logistic support, institutional arrangements, and organizational procedures. In brief, the general objectives of the Regional Study as provided in the contract covering the preparation of this Prospectus are as follows:

- Develop and apply techniques to permit meaningful predictions of the distribution of both stable and reactive pollutants over distances of 150 kilometers.
- Improve the understanding of atmospheric reactions associated with SO_2, NO_x, hydrocarbons, ozone, organic nitrates, and aldehydes.
- Define an optimum network to measure and monitor air quality and meteorological phenomena within a typical air quality control region.
- Prepare methods to obtain and update emission inventories within a region and develop such an inventory for the selected region.

The principal site selection criteria for the Regional Study include the following:

- Climate--The site should possess a climate representative of a large proportion of the major urban regions in the nation. It should permit experimental work throughout the greatest possible portion of the year.
- Heterogeneous Emissions--The site should have a broad spectrum of emissions as determined by fuels consumed, industrial production processes, and the current pollution mix. An important specific factor is the extent of coal usage because of its relationships to both sulfur oxide and particulate emissions.
- Surrounding Area--This criterion includes measures of the isolation of the site from other major sources of pollutants and

the presence of a rural fringe. Sites in close proximity to large bodies of water should be avoided because of their climatic influences and their constraint on the location of air quality and meteorological instruments.

- Area Size--The criterion of area size provides a general measure of the expected scope and magnitude of the Regional Study for each candidate site.

- Pollution Control Program--The various candidate areas have considerable variation in their existing control programs. It appears desirable for the Regional Study to be carried out at a site where the control program is generally well developed but can be significantly improved. Such a site would provide a background of data and general experience that could be used to establish the Regional Study. In addition, an existing program could provide initial contacts with industrial sources for the gathering of source inventory data.

- Historical Information--Historical data, including meteorological and pollution, applicable to a site also vary widely. In general, a site tends to be more attractive as the quantity of historical data increases. Care must be exercised, of course, to distinguish between quantity and quality.

The selected region should represent to the greatest possible degree all other regions in the nation. On the basis of climatology, atmospheric chemistry and physics, and emission sources, a region must be selected that combines the most important characteristics of all separate regions. At the same time the region should be comparatively "simple" with respect to these characteristics. That is, since the state of the art in pollution modeling and prediction has many limitations, some of which should be eliminated by the Regional Study, the accepted scientific approach is to proceed from the simple to the complex. Accordingly, the region ought not encompass unusual and difficult to treat topographical and relief features, which may markedly affect and interact with the synoptic and mezoscale meteorological factors or for any reason may cause the geographical pattern of location of the emission sources to be unusually configured. The selection of a simple area, moreover, may tend to permit the use of a relatively small number of meteorological and air quality monitoring instrument stations.

The Regional Study interaction with the local pollution control program will be most beneficial. Clearly, however, the region must have all pollutants in its atmosphere which are intended to be examined in the course of the study. Moreover, the quantities of each pollutant should be present in substantial amounts to minimize the need for highly sensitive instruments and elaborate facilities.

The criterion that the region should have a reasonably well-defined set of areas to permit accurate measurements, inventorying, and related activities associated with each of the study goals leads to the following minimum requirements:

- One or more heavily industrialized sections containing a broad spectrum of manufacturing and processing facilities producing the required range of pollutants

- A well-defined pattern of vehicular traffic flows, including a distinct central business district

- A generous rural fringe or annulus containing agricultural crops and other vegetation, which may be affected by the various pollutants. The rural fringe should be extensive enough to permit pollutant monitoring at distances up to 100 kilometers from the principal pollutant sources.

These requirements on land usage within the region indicate that the region should be relatively isolated from other principal pollution sources. Moreover, they tend to limit the size of the region. While difficult to quantify at the present time, the diffusion models themselves and their required computer capacities impose certain ceilings on the number of input elements and the atmospheric volumes which can be treated at any one time. Additionally, design and funding requirements for meteorological and air quality instrumentation must be recognized and can easily impose limitations upon the size of the region. By the same token, the time and effort needed to develop a comprehensive emission inventory of a region will surely act as at least a secondary restraint on region selection.

In the event of modest rather than substantial separation between the region and a second major emission complex, the need may arise for selected instrumentation to monitor pollution levels in the region caused by emission sources elsewhere. The character and extent of such facilities are uncertain, but their design might well require procedures similar to that for the regional system itself. However, selection of the region should be made to minimize and hopefully eliminate the need for these facilities.

Method of Analysis

The examination of all potentially suitable regions leading toward selection was carried out in phases. First, the nation as a whole was summarily viewed on a gross climatological, coal use, and regional separation basis. This procedure permitted the elimination of both east and west coastal regions from further consideration. Second, within the remaining area, all SMSAs with populations in excess of 400,000 for a total of 33 were analyzed to determine the following characteristics:

- Geographical separation from other candidate SMSAs and all other SMSAs
- Population concentrations and area size
- Existing pollution levels of representative types.

The results of this analysis lead to the elimination of 20 SMSAs. The remaining 13 were examined with respect to the manufacturing industry existing in the SMSA to provide measures of the possible variation in the types of pollutants. Industrial activity was also characterized by its value added by manufacture to gain a qualitative measure of possible emission intensities. This review permitted the elimination of selected additional SMSAs because of a relative lack of industrial concentration.

The final group was treated on a more subjective basis with respect to the following criteria:

- Area size
- Climatological conditions affecting or prohibiting experimental operations
- Geographical and political conditions affecting instrument locations.

Four SMSAs remained at the conclusion of this final screening process. Although the existence of a pronounced rural fringe was virtually insured by the criteria of SMSA separation, the final four candidate SMSAs were examined in more detail with regard to agricultural activity. Even though agricultural activity was not examined within all counties expected to be included within the Regional Study, the criterion of separation combined with high agricultural activities within the SMSA itself provides a confident expectation of a highly suitable rural fringe in the Regional Study area.

National Summary Analysis

Meteorology

The site of the Regional Study should be selected within an area where the climate is generally representative of the greatest possible portion of the nation. Translation of research findings and application to other urban areas should be greatly facilitated by such a location.

The nation's climate can be generally classified into four types. The first is termed the Continental. In general, the western limits of the Continental climate are the Cascade-Sierra Nevada-Coast Range system, while the eastern limit tends to follow the eastern slopes of the Appalachian Chain. The southern limit is somewhat less distinct but roughly parallels the Gulf Coast at distances 200-250 miles inland. Although significant differences exist in virtually all climatological factors from north to south and east to west within this area, there is nevertheless an overall sense of commonality within the area and sharp differences with the remainder of the nation. The climatic homogeneity increases markedly within the area east of the Rockies.

The second type of climate includes the Pacific Coast areas west of the Cascade-Sierra Nevada-Coast Range system. The Pacific Coast climatic region has several distinct components ranging from the California or Mediterranean type to the Marine of the Oregon and Washington Coasts. Nevertheless, all are influenced by the Pacific Ocean and have mild winters and generally dry summers, and much less distinct seasonal variations are observed than in the Continental areas.

The third type includes the Atlantic seaboard north of approximately the 40th parallel. The general climate of the area is in some sense a derivative of the Continental type due to the prevailing westerly winds. However, the Atlantic Ocean constrains the seasonal variations so that both winters and summers tend to be more moderate than those of the Continental type.

The fourth climatic type, sometimes termed the Humid Subtropical, exists along the south Atlantic Coast and extends westward along the Gulf Coast to southeastern Texas. It is generally characterized by very hot humid summers and normally mild winters but with occasional very cold periods. Rainfall occurs throughout the year. Seasonal changes are far less pronounced than in the Continental climate. Storm disturbances tend to be more frequent and severe than in other climatic areas of the nation.

Since the Continental climate indeed embraces the largest portion of the nation, this area would appear most appropriate as the Regional Study site. Care should be taken, however, in selecting the site, so that the greatest possible period of the year can be used for the conduct of research experiments. This provision tends to exclude the northern portions of the area in which lengthy winter periods could hamper or indeed prevent field work for periods of as much as four to five months.

Fossil Fuels

The types and quantities of fossil fuels used within the region will influence the nature of the pollutants, the content of the emission inventory, and the procedures developed for control. Accordingly, it is eminently desirable that the region include emission sources using all types of fossil fuels in significant quantities.

Representative fuel usage for stationary sources can be typified by public utility practices. Fossil fuels used in electric power generation consist almost exclusively of coal, fuel oil, and natural gas. Very small quantities of diesel oil, gasoline, and other fuels are used for some standby and peaking generating units. Nationally, coal accounts for approximately 60% of power generation, while fuel oil and natural gas stand at 10 and 30%, respectively. Long term trends show natural gas claiming an increasing share at the expense of coal, with fuel oil remaining relatively constant.

The examination of the geographical pattern of fossil fuel usage throughout the nation reveals significant differences among states and regions. The variations stem primarily from the differing costs of fuels from state to state but also results to some extent from pollution control programs which favor natural gas over coal. The general pattern of fossil fuel usage is shown in Figure X-1. The New England states principally use fuel oil, since it is readily available at relatively low cost by ocean tanker and barge transport. Most generating plants are near tidewater. At the other extreme, the Pacific Northwest states use virtually no fossil fuel because of the predominance of hydroelectric facilities.

The remainder of the nation can be approximately divided into coal and natural gas-using regions. The natural gas region includes the West South Central states, the Gulf Coast areas, portions of the Southwest, and California. The remaining areas and states, therefore, are predominantly coal users.

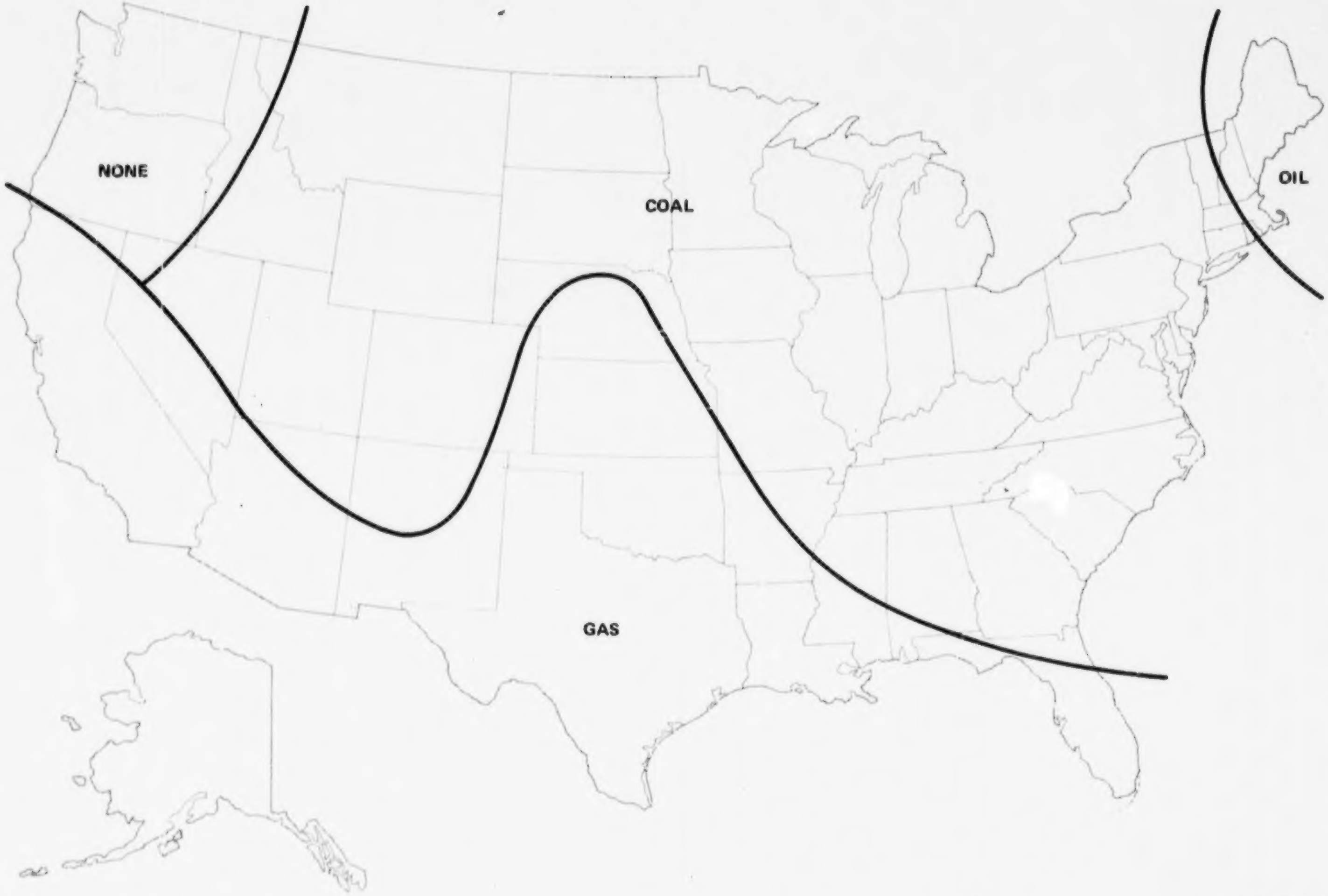

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FIGURE X-1 GENERAL PATTERN OF USAGE OF FOSSIL FUELS

The use of fuels by manufacturing industries tends to follow the same general pattern shown by utilities but with the coal-natural gas interface displaced northward. On the other hand, essentially no coal is used south of the interface. Likewise, commercial and residential space heating by gas is very common throughout the nation with the exception of New England. In fact, over 60% of the space heating in residential structures is accomplished by natural gas.

Regional Isolation

In considering the criteria of regional isolation, a summary map analysis should be sufficient for the purpose of focusing attention on the most suitable area of the nation for which a more detailed analysis will be appropriate. For purposes here as well as more detailed subsequent analysis, the use of the SMSA appears most appropriate as the basic unit of measure. However, since the definition of an SMSA is based upon population and county boundaries, some distortion in gaging isolation of candidate regions may arise. For example, the Las Vegas SMSA is adjacent to the San Bernardino-Riverside-Ontario SMSA. However, the population and economic activities of both are concentrated within a very small area within each SMSA and are separated by over 200 miles. Thus, in fact, a high degree of isolation may actually exist in adjacent areas.

With this limitation in view, the geographical pattern of SMSAs nevertheless reveals an exceptionally high concentration in two areas of the nation. The first includes the well-known Washington, D.C.-Boston corridor in which the SMSAs are virtually continuous and have heavy concentrations of industry, electric power central stations, transportation facilities, and other emission sources throughout its length. Moreover, the residential population is sufficiently dense and widespread to prevent most of the area from having a suitably expansive rural fringe necessary for the study. These conditions present extreme problems in defining a region in terms of both a consolidated set of pollution sources which can be considered as a unit and a pollution receptor area which is clearly coupled with the sources. Accordingly, unless other compelling reasons arise, the selected region should best not be within the Washington-Boston corridor.

The second area showing somewhat the same characteristics is the industrial crescent around the south and east of Lake Erie from Cleveland through Toledo to north of Detroit. Although the pollution sources through the area tend to be more closely grouped or form less of a continuous band than the Washington-Boston corridor, the possibility of their interaction in receptor areas nevertheless is likely to occur.

However, rather than totally discard candidate regions in this area at this point, they will be retained for more detailed analysis.

Results

The combination of noncoal usage and the lack of a representative climate provides the basis to eliminate the Pacific Coast area from further consideration. Lack of coal use west of the Rocky Mountains to the Pacific Coast area discourages further consideration of this area as well. (Of course, few, if any, suitable sites exist in this latter area.) The southwest and south central regions and the southmost fringe of the southern states also can be ruled from further consideration by the combination of somewhat atypical climatic conditions and the almost complete exclusion of coal. Finally, the Atlantic seaboard east of the Appalachian Mountains is unsuitable due to the general complexity ~~of the~~ area, intense industrial and urban development, and the lack of a clearcut representative climate and well-defined rural fringe.

General Analysis of Standard Metropolitan Statistical Areas

The foregoing process of selection permits the narrowing of focus to candidate sites situated east of the Rocky Mountains, west of the Appalachian divide, and north of approximately the 32nd parallel, except for those included in the northward excursion of the natural gas-coal interface. A total of 33 SMSAs are situated within the area with populations greater than 400,000. SMSAs smaller than 400,000 are excluded from further consideration because they tend to lack an adequate industrial mix, transport, and other features necessary for the Regional Study. These SMSAs plus an additional four in the noncoal region are shown in Table X-1. The latter four are intended to show certain variations in characteristics from the prime candidate site.

Table X-1 shows for each candidate SMSA a number of descriptors for the following characteristics:

Levels of Representative Pollutants--The Regional Study is expected to focus on a large number of pollutants. Accordingly, the region selected for study must have them in sufficient concentrations to permit thorough analysis. Comparatively high levels of pollutants are desirable to reduce the need for highly sensitive instruments and associated physical and chemical analysis. Moreover, it is likely that all candidate regions will be engaged in active control and abatement programs during the

Table X-1

SELECTED CHARACTERISTICS OF CANDIDATE SMSAs

	Hydrocarbons $T/mi^2/day$		Oxides of Nitrogen $T/mi^2/day$		Oxides of Sulfur $T/mi^2/day$		Annual Mean Suspended Particles	Nearest SMSA		Nearest Candidate SMSA					
	Central City	SMSA	Central City	SMSA	Central City	SMSA		Boundary	Central City Separation	Boundary	Central City Separation	P95	P50	Possible Sunshine Percent	Degree Days
1. Akron	0.482	0.075	0.511	0.088	2.199	0.343	134	0	20	0	30	20	5	n.a.	6,345
2. Albany-Schenectady-Troy	0.642	0.034	1.204	0.063	4.618	0.243	86*	10	30	50	120	10	9	54	6,825
3. Atlanta	0.505	0.072	0.379	0.054	1.115	0.159	97	40	80	90	140	19	7	61	2,961
4. Birmingham	0.382	0.054	0.652	0.091	1.500	0.211	142	0	40	90	140	28	6	58	2,779
5. Buffalo	0.706	0.071	0.751	0.075	2.366	0.238	139	0	70	0	70	22	6	53	7,213
6. Chicago	0.636	0.164	0.705	0.182	3.100	0.800	124	0	0	0	0	36	10	58	6,113
7. Cincinnati	0.432	0.049	0.677	0.076	3.719	0.419	154	0	10	0	40	24	7	58	4,806
8. Cleveland	0.322	0.124	0.346	0.134	1.068	0.413	116	0	10	0	30	27	7	52	6,432
9. Columbus	0.062	0.060	0.392	0.038	0.680	0.066	124	10	40	10	70	24	5	57	5,444
10. Dallas	0.210	0.037	0.170	0.030	0.013	0.002	101	0	30	0	30	35	7	66	2,363
11. Dayton	0.631	0.046	0.666	0.049	2.776	0.203	143	0	30	0	40	22	5	58	5,606
12. Denver	0.214	0.010	0.450	0.020	1.613	0.073	126	30	60	300	350	24	6	70	5,982
13. Detroit	0.590	0.221	0.610	0.228	2.145	0.804	161	0	30	0	50	26	10	54	6,275
14. Flint	0.641	0.037	0.416	0.024	1.096	0.063	n.a.	0	50	0	50	21	5	n.a.	7,007
15. Fort Worth	0.253	0.043	0.210	0.035	0.010	0.002	133	0	30	0	30	20	5	n.a.	2,405
16. Gary-Hammond-East Chicago	n.a.	0.072	n.a.	0.150	n.a.	0.616	164	0	0	0	0	17	7	58	6,113
17. Grand Rapids	0.577	0.037	0.487	0.031	1.732	0.111	n.a.	20	50	70	100	26	5	48	6,894
18. Houston	0.409	0.028	0.556	0.039	0.019	0.001	102	0	40	100	200	42	7	66	1,278
19. Indianapolis	0.783	0.043	0.674	0.037	3.072	0.168	154	0	30	30	100	27	6	60	5,699
20. Kansas City	0.447	0.046	0.362	0.037	0.411	0.042	103*	0	50	150	260	22	7	64	4,868
21. Louisville	0.614	0.093	0.970	0.145	4.950	0.741	148	40	70	40	100	13	5	58	4,718
22. Memphis	0.440	0.051	0.444	0.051	0.868	0.099	115	80	140	140	210	17	6	65	3,116
23. Milwaukee	0.328	0.125	0.349	0.133	1.890	0.721	150	0	20	20	100	25	6	56	7,635
24. Minneapolis-St. Paul	0.255	0.080	0.222	0.069	0.538	0.168	94*	70	140	230	300	19	7	58	8,394

Table X-1 (Concluded)

		Hydrocarbons T/mi^2/day		Oxides of Nitrogen T/mi^2/day		Oxides of Sulfur T/mi^2/day		Annual Mean Suspended Particles	Nearest SMSA		Nearest Candidate SMSA					
		Central City	SMSA	Central City	SMSA	Central City	SMSA		Boundary	Central City Separation	Boundary	Central City Separation	P95	P50	Possible Sunshine Percent	Degree Days
25	Nashville	0.443	0.035	0.556	0.044	3.162	0.250	115	60	120	110	150	24	5	58	3,578
26.	Oklahoma City							107	30	100	30	100	21	5	68	3,844
27.	Pittsburgh	0.425	0.073	0.886	0.153	3.948	0.680	151	0	30	30	100	30	9	55	[illegible],987
28.	Rochester	0.582	0.028	0.496	0.024	2.420	0.118	106	0	70	0	70	37	4	55	6,748
29.	St. Louis	0.717	0.084	0.843	0.066	3.722	0.292	170	40	90	150	250	29	8	58	4,809
30.	San Antonio	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	73	10	80	100	200	16	5	62	1,549
31.	Syracuse	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	161	0	40	10	80	32	5	51	6,756
32.	Toledo	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	92	0	60	0	60	25	5	59	6,491
33.	Youngstown-Warren	0.484	0.050	0.705	0.074	2.142	0.224	138*	0	50	0	50	20	6	n.a.	6,212

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n.a. = not available.

* Average of stations in area.

course of the Regional Study, so that selection of a region with initially high levels will perhaps provide indices for use in the study of the effectiveness of the programs.

Arithmetic mean annual measures of three important pollutants are shown in Table X-1 and include emission levels in tons per square miles of hydrocarbons, oxides of nitrogen, and oxides of sulfur for both SMSA and the central city. Additionally, the annual mean levels of suspended particles in micrograms per cubic meter are shown for the central cities.

Degree of Isolation--The region should be somewhat isolated from other comparable areas to provide for a suitable rural fringe, to permit a well-defined emission inventory, and otherwise to minimize interaction of the study region with outside pollution sources. Three measures are provided. The first is the distance from the candidate SMSA boundary to the nearest SMSA and the corresponding distance between the principal cities of each SMSA. The second is the distance from the candidate SMSA boundary to the nearest other candidate SMSA and the corresponding distance between the principal cities of the two SMSAs. The last includes the radius of a circle enclosing 50 and 95% of the population of the SMSA which provides a general measure of concentration and the urban-rural mix.

Possible Sunshine--Since some of the pollutants to be considered include those resulting from photochemical reactions, a measure of sunshine in the region is of interest. The percentage of actual sunshine to the maximum possible is shown.

Degree Days--The mean annual degree days with a base of 65°F is the mean of the annual sums of the differences between 65°F and the daily mean below 65°F. This measure provides an indication of space heating requirements and the possible corresponding pollutant levels from fuel usage.

Pollutants

The ranges of pollutant emissions and suspended particles within the regions show wide variations as summarized in Table X-2.

In general, areas having high emission levels for one pollutant show correspondingly high levels for most others, although significant variations from this pattern are noted. To ensure adequate pollution levels for the Regional Study, it is preferable to select a region with moderate

Table X-2

RANGE OF POLLUTANT LEVELS OF THE CANDIDATE SMSAs

Pollutant	Central City Maximum	Central City Minimum	SMSA Maximum	SMSA Minimum
Hydrocarbons, tons/mi^2/day	0.783	0.062	0.221	0.010
Oxides of nitrogen, tons/mi^2/day	1.204	0.176	0.228	0.020
Oxides of sulfur, tons/mi^2/day	4.950	0.010	0.804	0.002
Suspended particulates, μg/m^3	170	73	n.a.	n.a.

to severe levels of all pollutants. Accordingly, Table X-3 provides a ranking of the top 15 SMSAs and central cities for each pollutant. (Cities are denoted by their number as shown in Table X-1.)

Table X-3

CANDIDATE SMSAs RANKED BY POLLUTANT LEVELS

Rank	Hydrocarbons Central City	Hydrocarbons SMSA	Oxides of Nitrogen Central City	Oxides of Nitrogen SMSA	Oxides of Sulfur Central City	Oxides of Sulfur SMSA	Particulates Central City
1	17	13	2	13	19	13	26
2	26	6	19	6	2	6	15
3	5	21	24	24	24	19	28
4	2	8	26	15	26	21	13
5	31	19	5	19	7	24	17
6	6	26	6	8	33	15	7
7	11	22	7	21	6	7	24
8	19	1	17	4	17	8	21
9	13	24	11	1	11	1	9
10	25	3	4	7	15	26	11
11	3	15	13	5	5	33	4
12	30	5	16	22	1	2	5
13	1	9	33	26	13	5	30
14	18	4	1	2	21	4	1
15	20	20	25	3	12	11	14

As can be noted from Table X-1, pollutant data were not readily available for seven candidate areas. However, within reasonable limits the areas without such data can be taken as being equivalent to other areas as shown below.

Area	Equivalent Area
Oklahoma City Tulsa San Antonio	Dallas
Salt Lake City	Denver
Syracuse	Rochester
Toledo	Cleveland

These top 15 areas can be narrowed for further consideration on the basis that the SMSAs and central cities should each rank in the top 15 for at least all but one pollutant or show the highest level for at least one pollutant. A total of 13 SMSAs meet this criterion as follows:

Akron
Albany-Schenectady-Troy
Birmingham
Buffalo
Chicago
Cincinnati
Dayton
Detroit
Gary-Hammond-East Chicago
Indianapolis
Louisville
Pittsburgh
St. Louis

Manufacturing

The pollutant levels within the candidate SMSAs are generally related to the sheer size of the population, the number and use patterns of motor vehicles, and similar factors. Additionally, emission levels are potentially related to the size and type of manufacturing industry located in the SMSA. Table X-4 shows the type and magnitude of 15 different manufacturing industries in the 13 SMSAs having high emission levels. Manufacturing activity is classified by the Standard Industrial Classification (SIC) three-digit groups for each SMSA. The table indicates the SMSA rank

Table X-4

RANKING OF CANDIDATE SMSAs BY VALUE ADDED BY MANUFACTURE FOR SELECTED THREE-DIGIT SIC GROUPS

SMSA	262	265	281	282	237	291	301	321	324	327	331	332	333	334	336
1. Akron	--	* /0.07	41/0.49	68/0.40	* /0.01	--	1/31.68	--	--	75/0.25	* /0.02	33/0.71	--	--	108/0.12
2. Albany-Schenectady-Troy	21/1.41	41/0.50	76/0.21	33/1.22	* /0.07	--	--	--	11/1.46	91/0.22	47/0.27	5/3.34	--	--	* /0.02
3. Birmingham	--	95/0.18	86/0.17	--	13/1.75	102/0.05	--	--	3/2.36	27/0.64	3/7.35	11/2.39	--	13/1.33	86/0.17
4. Buffalo	44/0.79	15/1.16	5/3.80	31/1.26	3/3.41	26/0.77	19/1.20	--	21/1.01	19/0.77	7/3.71	10/2.47	--	29/0.88	43/0.43
5. Chicago	132/0.10	2/8.70	13/2.16	17/1.85	12/1.80	4/8.20	* /0.01	--	19/1.19	3/2.71	1/14.76	1/6.84	41/0.53	1/16.37	1/11.27
6. Cincinnati	73/0.37	11/1.33	34/0.59	52/0.56	31/0.78	60/0.20	--	--	--	35/0.54	42/0.33	37/0.62	14/1.56	18/1.06	25/0.80
7. Dayton	74/0.37	52/0.36	* /0.04	--	127/0.12	--	16/1.29	--	14/1.38	34/0.55	* /0.03	15/1.64	--	--	27/0.78
8. Detroit	177/0.11	18/1.09	19/1.15	65/0.42	71/0.26	11/1.96	6/4.13	4/7.46	6/2.15	5/1.69	4/5.81	9/2.89	75/0.05	8/2.16	5/3.75
9. Gary-Hammond-East Chicago†															
10. Indianapolis	--	28/0.67	118/0.11	--	42/0.54	64/0.15	21/1.17		--	36/0.50	* /0.02	25/0.90	--	49/0.34	82/0.20
11. Louisville	--	25/0.75	29/0.63	6/2.86	46/0.46	65/0.15	--		17/1.37	57/0.35	--	39/0.60	--	64/0.13	* /0.01
12. Pittsburgh	139/0.05	14/1.21	31/0.61	37/0.98	--	61/0.15	* /0.01	2/0.29	22/1.01	17/0.80	2/13.7	3/3.50	29/0.95	23/0.93	10/1.82
13. St. Louis	--	7/2.34	7/3.61	* /0.05	9/2.12	9/2.66	35/0.34	9/5.55	7/1.87	15/0.92	13/1.58	8/2.89	13/1.73	6/2.93	8/2.41

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* Unavailable but lower ranking than all other SMSAs.

† Incorporated with Chicago SMSA.

Source: Location of Critical Industries, Stanford Research Institute, October 1969.

in production for each group and its percentage of the national value added by manufacture for each SMSA. The SIC three-digit groups are:

262	Paper mills, except building paper mills
265	Paperboard containers and boxes
281	Industrial inorganic and organic chemicals
282	Plastics materials and synthetic resins, synthetic, rubber, synthetic and other man-made fibers, except glass
287	Agricultural chemicals
291	Petroleum refining
301	Tires and inner tubes
321	Flat glass
324	Cement, hydraulic
327	Concrete, gypsum, and plaster products
331	Blast furnaces, steel works, and rolling and finishing mills
332	Iron and steel foundries
333	Primary smelting and refining of nonferrous metals
334	Secondary smelting and refining of nonferrous metals
336	Nonferrous foundries.

Production facilities for the three-digit manufacturing groups are found in most of the candidate SMSAs. Flat glass, SIC 321, however, is limited to three SMSAs and primary smelting and refining of nonferrous metals, SIC 333, is limited to five. Only the Detroit SMSA has manufacturing activity in all 14 three-digit groups.

Blast furnaces, steel works, and rolling and finishing mills, SIC 331, exist in all but the Louisville area. The ranges of value added by manufacture lie between Chicago at 14.76% to Akron and Indianapolis at 0.02% each. The development of a strict definition of the ideal mix of industry in SMSA does not appear possible or necessary. It is nevertheless desirable that the area have the widest possible mix with perhaps the industries somewhat in balance. Such a condition would permit a more comprehensive emission inventory analysis and ensure the largest possible number of pollutant types. In this regard, the St. Louis SMSA tends to show perhaps the most satisfactory industrial mix without undue concentration of a single industry. The area generally ranks in the range of sixth to twelfth in the nation for most industrial groups represented. On the other extreme is the Akron SMSA with very low levels of production in all three-digit groups except for the overwhelming first-place position or 31.68% of production for SIC 301, tires and inner tubes.

Broadly, on the basis of current manufacturing activities, the following SMSAs appear most suitable.

Birmingham--Although dominated by SIC 331, blast furnaces, steel works, and rolling and finishing works, and related industrial groups and lacking significant SIC 291, petroleum refineries, the SMSA shows a reasonably comprehensive industrial mix.

Buffalo--The SMSA is not significantly dominated by any particular industrial group and is one of the few candidate areas with any significant capacity in SIC 262, paper mills, which is, of course primarily in northern non-SMSA counties of the nation.

Chicago--The area presents a very attractive industrial mix with almost all groups represented to a major degree but perhaps to an excessive degree for the Regional Study resources.

Cincinnati--The area presents a relative balance among industrial group sizes but with the general scope of operations somewhat limited, except for appreciable production in SIC 333, nonferrous metals, not shared by most candidate regions.

Detroit--As in the case of Chicago, the Detroit SMSA includes an advantageous set of industrial groups without significant dominance by any of the principal polluting industries.

Pittsburgh--As in the case of Birmingham, the industrial facilities are dominated by SIC 331 and SIC 332. However, sufficient capacities are noted in most other groups to maintain some balance.

St. Louis--The SMSA tends to have the best combination of industry of all candidate areas with no single three-digit group in dominance. The area has significant petroleum refining, SIC 291; hydraulic cement, SIC 324, industry exceeded only by Chicago and Birmingham; and has appreciable capacity in both ferrous and nonferrous metals. The chemical group is also present to a major extent.

Geographical Separation

The extent of candidate SMSA separation as provided in Table X-1 is summarized in Table X-5 for distances between central cities.

Table X-5

SEPARATION OF CENTRAL CITIES OF CANDIDATE SMSAs
(Miles)

500-200	200-100	100-50	50-0
Denver	Albany-Schenectady-Troy	Buffalo	Akron
Houston	Atlanta	Columbus	Chicago
Kansas City	Birmingham	Detroit	Cincinnati
Memphis	Grand Rapids	Flint	Cleveland
Minneapolis-St. Paul	Indianapolis	Rochester	Dallas
Oklahoma City	Louisville	Syracuse	Dayton
St. Louis	Milwaukee	Toledo	Fort Worth
San Antonio	Nashville	Youngstown-Warren	Gary-Hammond-East Chicago
	Pittsburgh		

The SMSAs in the 500-200 mile group generally tend to be the most appropriate for the Regional Study. Interarea pollution should be minimal. and the larger distances suggest the existence of suitably extensive rural areas. Similar but less pronounced characteristics likely can be attributed to the 200-100 mile group. The SMSAs with central city spacings less than 100 miles generally appear as undesirable. Interarea pollution effects may be likely which might force the Regional Study to consider the two adjoining SMSAs perhaps in complete detail. This requirement could introduce needless complexity in the Regional Study and severely tax the available resources of the Study.

The relationship of the radius of circles containing 95% and 50% of the SMSA population provides a rough normalized measure of the proximity of the truly rural fringe of the SMSA to the desired centralized emission sources, or the extent of urban sprawl and the resulting diversity of emission sources. This relationship might be taken as a simple ratio of the two radii. As a general rule, the less the ratio the greater the degree of concentration to be expected. Rounded to the nearest whole number, the most favorable SMSA is the Albany-Schenectady-Troy SMSA with a ratio of unity. This case, however, is a statistical anomaly because the SMSA consists of three central cities rather than one. Most of the remaining ratios range from three to five with Syracuse at six and Rochester at an extreme of nine. On this general basis of comparison, therefore, most candidate regions tend to exhibit the same characteristics.

Sunshine

The percentage of possible sunshine as shown in Table X-1 ranges from a low of 48 in Grand Rapids to a high of 70 in Denver, but the bulk of the cities are in the high 50% to low 60% range. Since the extent and severity of photochemical reactions and resultant pollutant levels depend upon sunshine magnitudes, site selection should favor those areas with high percentates.

Space Heating

Lastly, the magnitude of space heating as related to the measure of degree days tends to have a wide range of values. The degree days vary from a maximum of 7007 in Flint, Michigan to a low of 1278 in Houston with a somewhat linear rate of increase from low to high. In general, this factor does not appear of primary importance in site selection but could become of significance in the selection between two otherwise virtually identical sites.

Results

Candidate SMSAs having features unsuitable for use as the site of the Regional Study are as follows.

Akron--The surrounding area tends to be congested, especially since the Cleveland SMSA is contiguous and its central city 30 miles north of Arkon. Rural fringe areas may be scarce. The prevailing winds tend to be southwesterly toward Cleveland and Lake Erie. Emission sources are overwhelmingly dominated by the rubber industry.

Albany-Schenectady-Troy--The area is attractive because of its isolation--120 miles to the nearest candidate SMSA--and its relatively high pollution levels. However, it lacks a geographically concentrated set of emission sources in that it has three central cities. Study in the area could be correspondingly and needlessly complex.

Buffalo--The prevailing winds tend to be southwesterly, thereby carrying the pollutants over Lake Ontario and largely eliminating significant rural fringe analysis. Winter climatic conditions in Buffalo are severe and could eliminate significant experimental efforts for about 40% of the year.

Chicago--The Chicago area is of considerable interest but must be eliminated for two principal reasons. First, its sheer size is a major disadvantage. Since Chicago is contiguous with the Gary-Hammond-East Chicago SMSA and almost indistinguishable from it, the Regional Study almost certainly would have to treat the entire complex. Such an area would probably strain the resources available for the Regional Study. Second and even more important, the prevailing winds in the area are south to southwesterly during the greater part of the year; this moves pollutants over Lake Michigan, largely eliminating the possibility of the rural fringe analysis.

Dayton--The Dayton SMSA lies in close proximity to other SMSAs and especially the significantly larger Cincinnati SMSA. The industrial mix in the Dayton SMSA is poor as it lacks a wide variety of representative installations.

Detroit--Detroit suffers from its sheer size and its nearness to other large and somewhat heavily industrialized SMSAs in both Michigan and Ohio. Interarea pollution would be likely and rural fringe areas may be limited. Additionally, the prevailing winds are to the east over Canada. Canadian involvement, while perhaps possible, would introduce an unnecessary complication in the Regional Study.

Indianapolis--The area has a limited industrial inventory. Heavy industry is represented to only a slight degree.

Louisville--As in the case of Indianapolis, the Louisville area lacks the spectrum of emission categories displayed by other candidate areas.

New York City--East coast areas, such as New York City, were eliminated because of a lack of individual industry and the predominant flow of pollutants over the ocean.

Los Angeles--California and Arizona locations were eliminated because of a general lack of coal combustion and sulfur emissions along with the dominance of automobile emissions over other sources.

Agriculture

The Regional Study should, if at all possible, be carried forth in a region having significant crop lands in the rural fringe. The extent to which a candidate area is isolated from other areas is suggestive of the presence of crop lands. Obviously, however, the nonexistence of SMSAs or similar land uses does not immediately imply usage to be allocated to agriculture. The terrain, soil conditions, climate, and a host of other factors can be such that the land is utilized for a wide range of other purposes. To portray the urban-rural relationship in terms of crop land usage, the chief candidate SMSAs are described in Table X-6 by county with respect to the total area used as farms and the percent of the total county land area in farms.

Counties of the Birmingham SMSA show a relatively small area devoted to agriculture although much of the area is somewhat rural in character. Much of the area consists of wooded rolling hills not particularly suitable for intensive agricultural activity, and thereby causes the area to be somewhat deficient for study of the interaction between urban pollution sources and rural crop lands.

Table X-6

AGRICULTURAL LAND USE IN CANDIDATE SMSA COUNTIES

SMSA	County and State	Total Acreage (thousands)	Percent of County Area
Birmingham	Jefferson, Ala.*	84	11.9%
	Shelby, Ala.	122	23.8
	Tuscaloosa, Ala.	235	27.3
	Walker, Ala.	114	22.0
Cincinnati	Clermont, Ohio	164	55.9
	Hamilton, Ohio*	53	20.1
	Warren, Ohio	187	71.4
	Boone, Kentucky	114	71.6
	Campbell, Kentucky	53	55.8
	Kenton, Kentucky	61	57.7
	Dearborn, Indiana	143	72.9
Pittsburgh	Allegheny, Pa.*	55	11.8
	Beaver, Pa.	80	28.4
	Washington, Pa.	328	59.8
	Westmoreland, Pa.	239	36.4
St. Louis	Franklin, Mo.	388	65.0
	Jefferson, Mo.	166	38.8
	St. Charles, Mo.	255	71.0
	St. Louis, Mo.	83	23.2
	St. Louis City, Mo.	†	†
	Madison, Ill.	346	74.1
	St. Claire, Ill.	312	72.8

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* Denotes central city county.

† Included in St. Louis County.

The Cincinnati SMSA consisting of seven counties shows comparatively intensive agricultural activity with six of the counties having crop acreage in excess of 50% and three in excess of 70%. Principal crops include corn for grain and for silage, and moderate plantings of clover, alfalfa, and soybeans. Some fruits, nuts, and vegetables are also grown. Thus, the Cincinnati SMSA appears to be quite suitable for the Regional Study for purposes of the analysis of urban pollutants on rural agriculture.

Pittsburgh, as in the case of Birmingham, presents a comparative lack of crop land with only one county of the SMSA supporting crop production in excess of 50% of the area. Several factors appear to contribute to the lack of agricultural activity, including the topography of the area which is characterized by flat-topped hills and steep-sided-stream valleys and the significant areas that have been given over to strip mines. Consequently, the Pittsburgh area does not appear altogether advantageous for the study of pollution-crop interactions.

The St. Louis SMSA, consisting of six counties plus St. Louis City, has four counties with land areas of 65% or more given to crop production. The principal crops include corn for grain and for silage, soy beans, and alfalfa. Additionally, considerable wheat harvest is included in the field crops. Since wheat is one of the principal food crops of the nation, its existence in the St. Louis area is regarded as particularly notable. A modest harvest of fruits, nuts, and berries originates in the SMSA. In light of these factors, the St. Louis SMSA appears to offer definite advantages over most areas in the analysis of the pollution impact on crops.

Chapter XI

NEAR-SURFACE ATMOSPHERIC RESEARCH FACILITY

General Considerations

Data gathering on both a routine and a special basis will be a fundamental activity carried out within the program of the Regional Air Pollution Study. Detailed information will be derived on both the meteorological and air quality conditions of the atmosphere throughout the region. Facilities will be provided so that these input data can be obtained both at ground level and at least to heights comparable with the surface mixing layer.

This discussion will consider the types of observations to be obtained for the Regional Study program. The design of the stationary regional air quality-meteorological monitoring network must consider three major factors: (1) the horizontal extent of the network, (2) station density and location, and (3) station characteristics.

Horizontal Extent of the Network

The horizontal extent of the monitoring network should be dictated by the physics of atmospheric transport and diffusion, and transformation processes in conjunction with the nature and location of emission sources. Ideally, the network should encompass the major center (or centers) of pollutant emissions such that the level of pollutant concentrations at the outer edge of the network is a very small fraction of the maximum concentrations that occur in the immediate vicinity of the emission sources.

Table XI-1 quantifies these considerations by presenting the ratio of theoretical (Gaussian model) values of predicted surface concentrations of an inert pollutant at a given range to the maximum ground level concentration from a continuous point source at each of three heights under the six Pasquill stability categories. Wherever possible, the distance is given where the ratio is reduced to 0.01; however, when this criterion cannot be satisfied, the ratio is given at the 100-km range. Table XI-1 also lists the distance from the source to the point at the

Table XI-1

VARIATION OF THE CONCENTRATION RATIO AND THE RANGE OF THE MAXIMUM SURFACE CONCENTRATION FOR A CONTINUOUS POINT SOURCE (FROM DATA PRESENTED IN SLADE, 1968)

Stability S	Source Height								
	10 m			30 m			100 m		
	Concn Ratio (percent)*	Range (km)	Max Concn Range (km)	Concn Ratio (percent)	Range (km)	Max Concn Range (km)	Concn Ratio (percent)	Range (km)	Max Concn Range (km)
A - extremely unstable	< 1	1	< 0.1	1	1	0.2	1	2	0.4
B - moderately unstable	1	1	< 0.1	1	2	0.2	1	5	0.7
C - slightly unstable	1	2	< 0.1	1	6	0.3	1	28	1.1
D - neutral	1	4	0.2	1	20	0.6	1.8	100	2.7
E - slightly stable	1	9	0.3	1	43	0.9	8	100	4.5
F - moderately stable	1	21	0.5	1.7	100	1.9	36	100	16

* The ratio of the surface concentration at a given range to the maximum surface concentration; the ratio is given at the range where it first equals 1% or at 100 km.

ground where the concentration reaches a maximum. For all cases except two, ground level concentrations at 100 km are reduced to at least 1 percent of the maximum surface value. The two exceptions occur for the tall stack case (100-meter height) under slightly and moderately stable atmospheric conditions. Under these conditions, the concentration ratios are 8 and 36 percent, respectively.

With these guidelines in hand, it seems reasonable, as a first-order approximation, to consider a nominal radius for the basic air monitoring network (Class A stations) of the order of 100 km from the centroid of the major emission sources. Figures XI-1, 2, and 3 are taken from the 1968 Report for Consultation on the Metropolitan St. Louis Interstate Air Quality Control Region (Missouri-Illinois). These figures give: (1) the location of major point sources of any single pollutant for the general region within a 100-km radius of downtown St. Louis, (2) the particulate emission density for the winter season, and (3) the sulfur oxide emissions for winter. Examination of these figures will show that, although the emission sources for the various pollutants are not necessarily coaligned, they are fairly well concentrated within a 35-km radius of downtown St. Louis at the Gateway Arch. Therefore, the minimum downwind distance between emission sources and the outer boundary of a 100 km-radius circular grid is seen to be on the order of 65 km. When reference is again made to Table XI-1, it will be seen that the large majority of stability and source-height cases still satisfy the 1-percent criterion at a range of 65 km. In fact, there are only two additional cases which do not; one case is again for the very tall stack situation (neutral stability) and the other case is for moderate stability with a moderate stack height. It therefore appears that the 100-km radius network is a reasonable, first-order grid size.

To obtain some idea of the concentration distribution downwind of a circular area source (35-km radius), some computations were made using a simple Gaussian dispersion model. The emissions region was represented by a series of approximately 500 point sources at a uniform height of 10 m. The distribution of the source strength about the region was represented in two ways: (1) all sources were assumed to be of similar strength (Q = 1), and (2) a circular Gaussian distribution of source strength was projected, where Q at the center was equal to unity and the one sigma value occurred at 17.5 km. Computations were then made for both source configurations under two classes of atmospheric stability--slightly stable and slightly unstable. The results are depicted in Figures XI-4 through XI-7. In all cases, the sharp decline in concentration immediately downwind of the source region is evident. Further downwind, computed concentrations with a slightly unstable atmosphere decrease almost logarithmically, while under slightly stable conditions the decrease is very gradual.

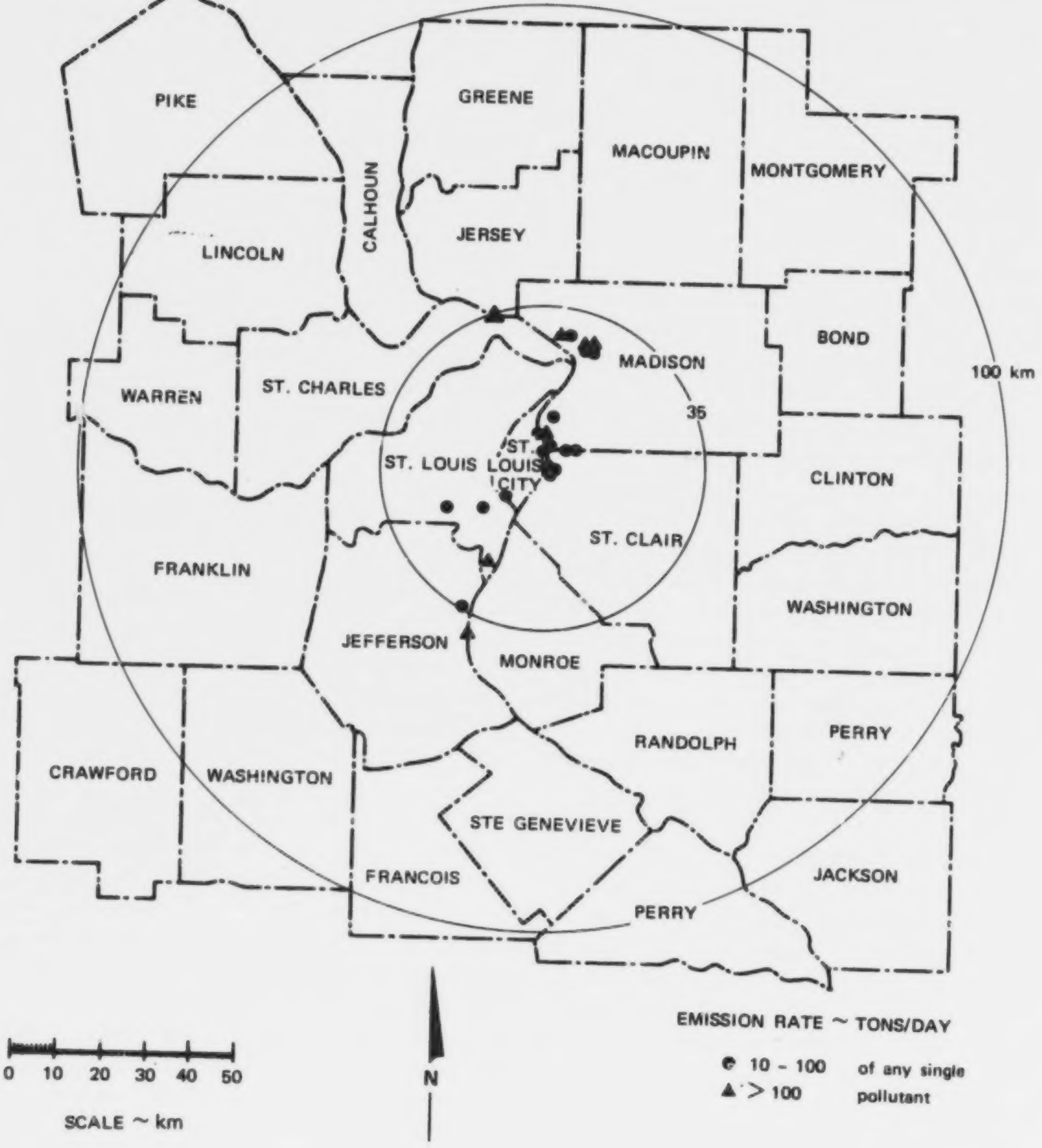

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FIGURE XI-1 MAJOR POINT SOURCES

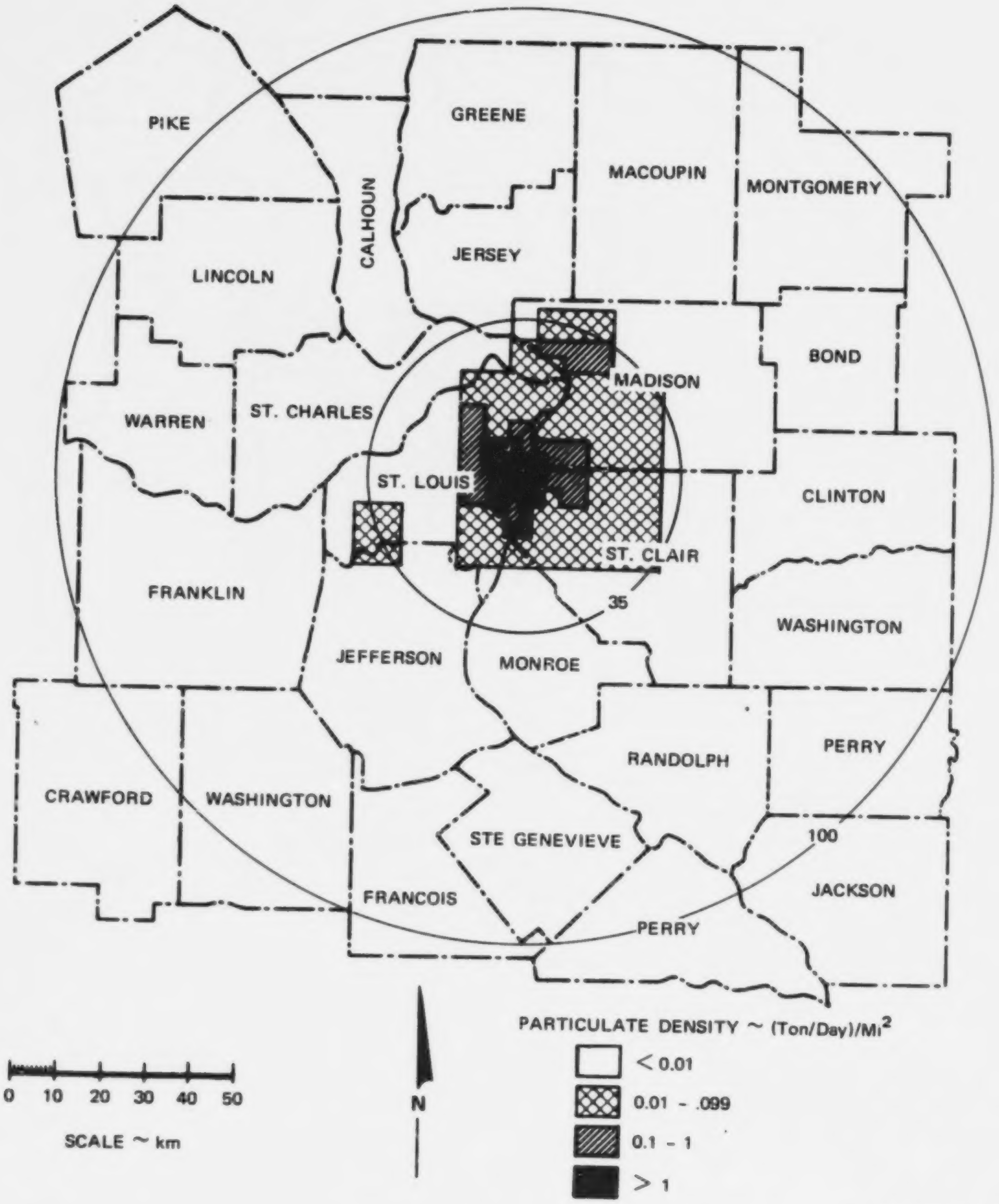

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FIGURE XI-2 PARTICULATE EMISSION DENSITY BY STUDY AREA ZONE, WINTER AVERAGE

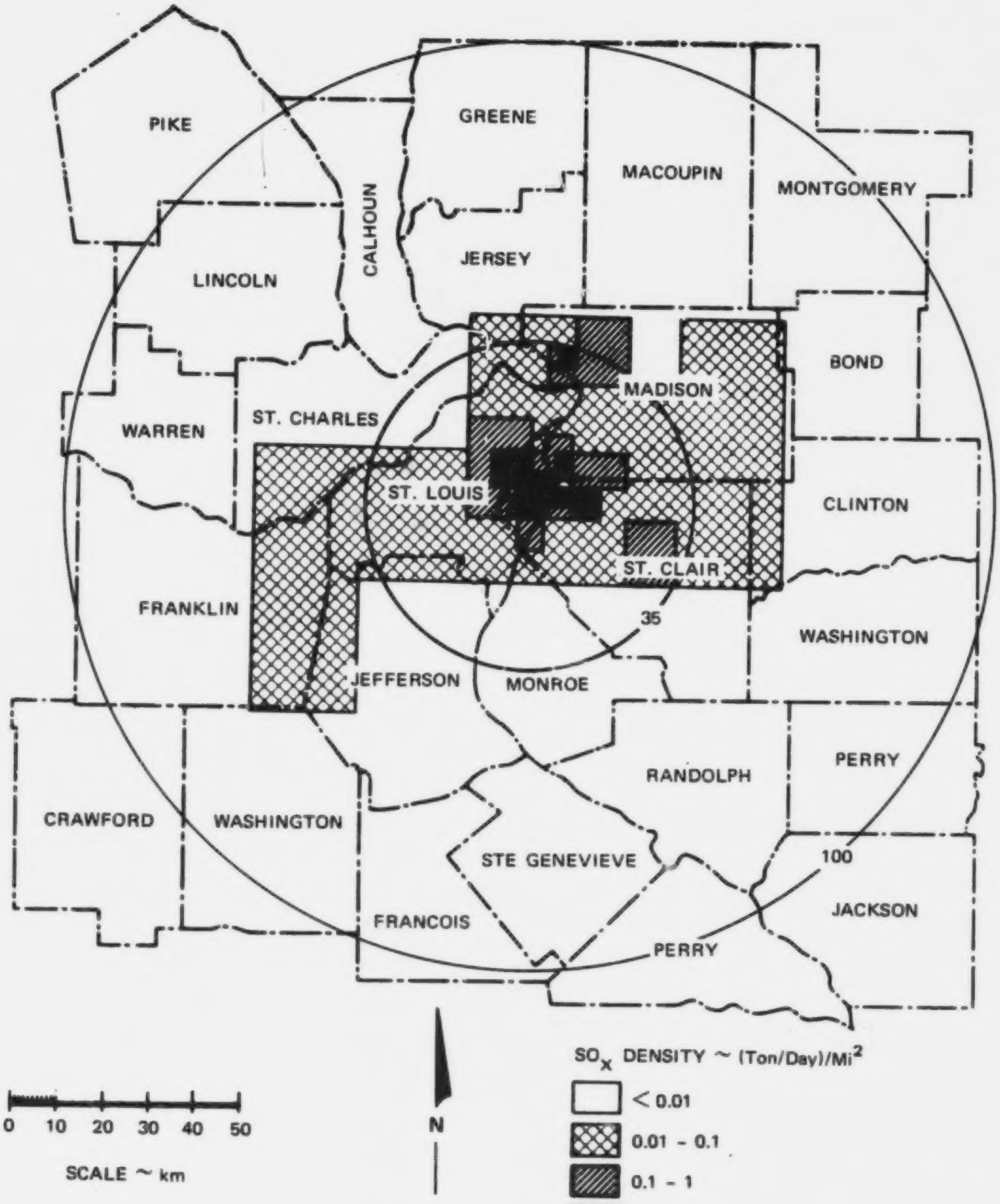

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FIGURE XI-3 SULFUR OXIDES EMISSION DENSITY BY STUDY AREA ZONE, WINTER AVERAGE

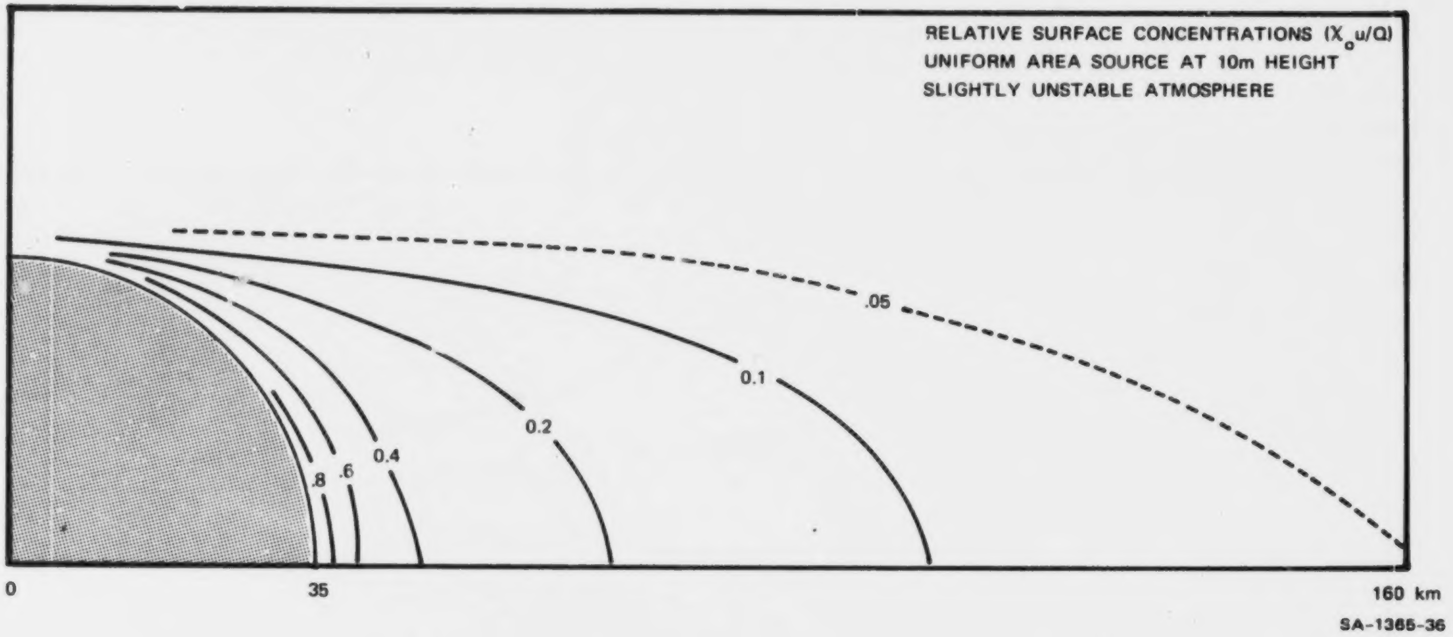

FIGURE XI-4 NORMALIZED VALUES OF SURFACE CONCENTRATION COMPUTED WITH A GAUSSIAN DISPERSION MODEL

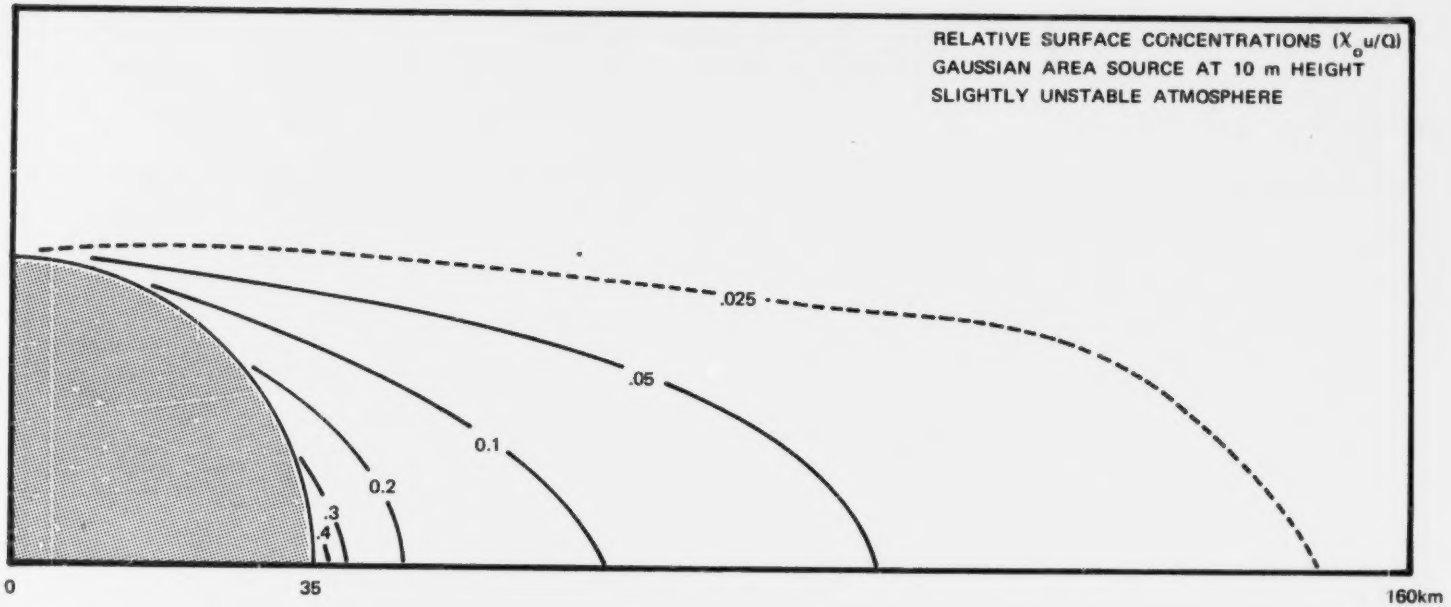

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FIGURE XI-5 NORMALIZED VALUES OF SURFACE CONCENTRATION COMPUTED WITH A GAUSSIAN DISPERSION MODEL

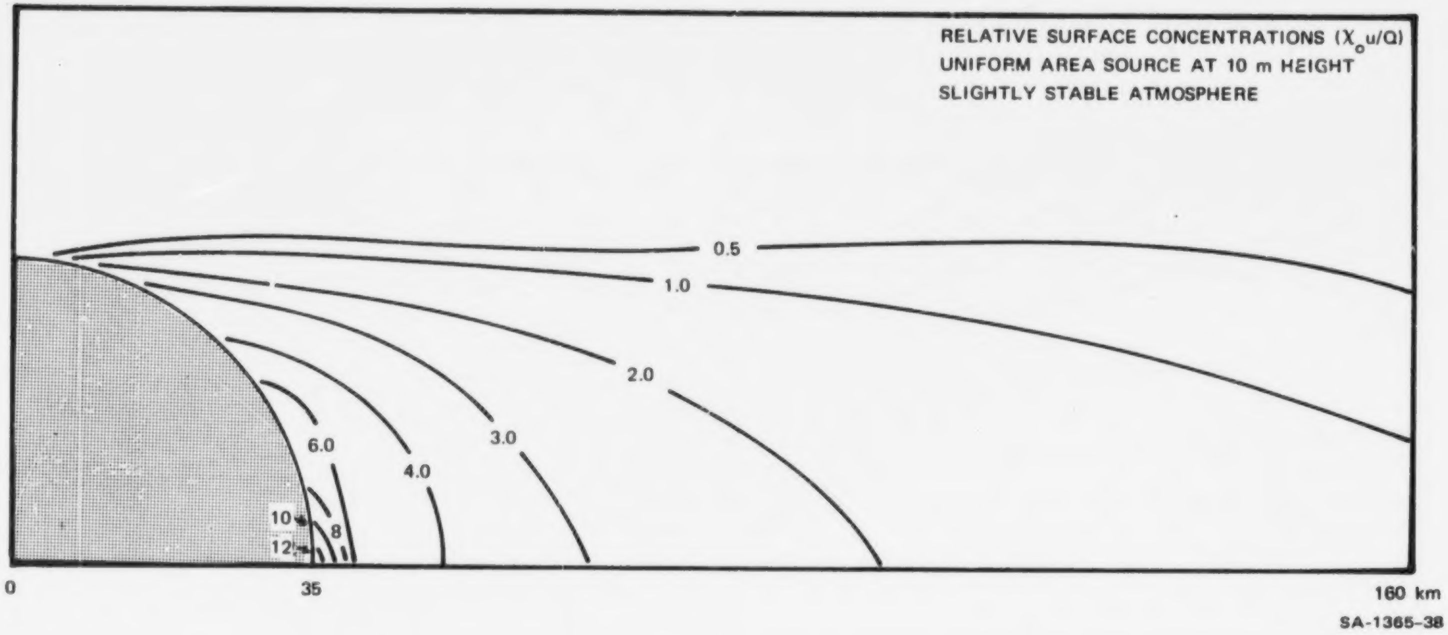

FIGURE XI-6 NORMALIZED VALUES OF SURFACE CONCENTRATION COMPUTED WITH A GAUSSIAN DISPERSION MODEL

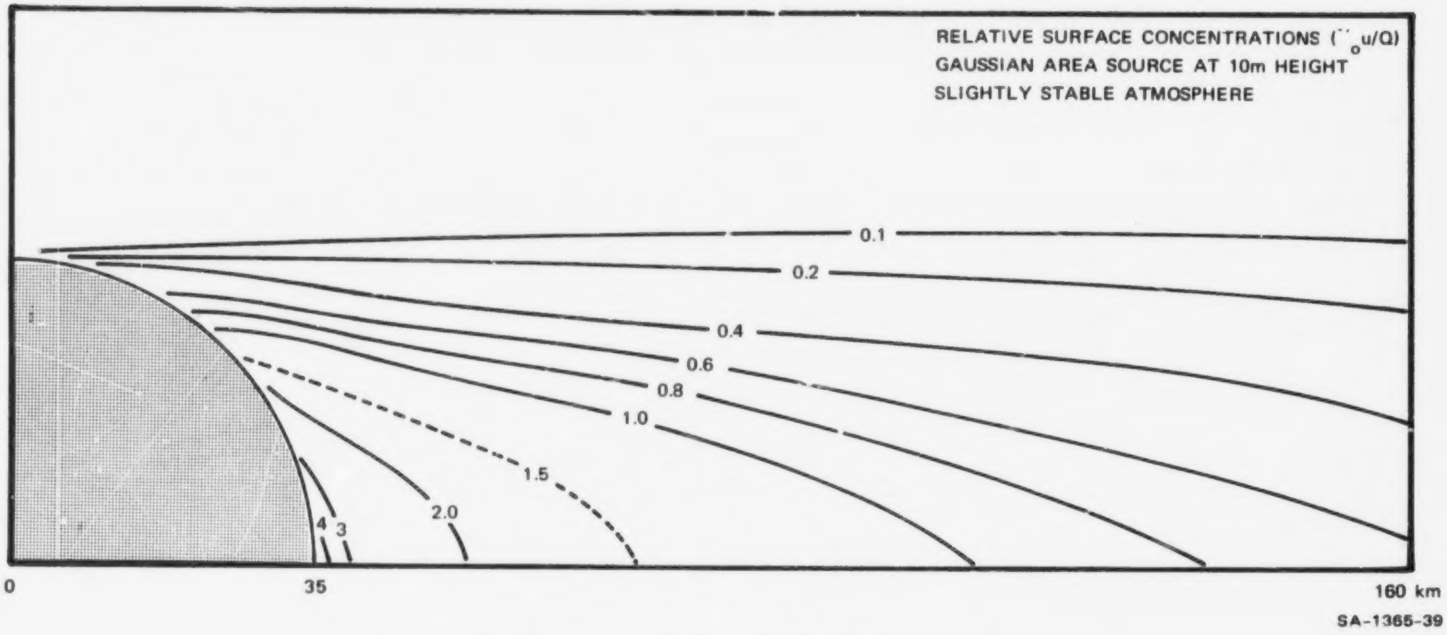

FIGURE XI-7 NORMALIZED VALUES AT SURFACE CONCENTRATION COMPUTED WITH A GAUSSIAN DISPERSION MODEL

This simple illustration points out the complexities introduced by atmospheric variations in locating fixed monitoring stations. A reasonable compromise might be the selection of the slightly stable atmospheric condition for establishing station spacing criteria due to the prime interest in periods of poor air quality. Of course, the concept of a concentrated circular area source is highly idealized and additional practical considerations must also be evaluated.

Although a 100-km range defines the nominally satisfactory horizontal scale (radius) for the surface network under most cases, it may be desirable to extend the range for the study of transport and diffusion from very tall source heights under stable conditions. The maximum extent of the surface network will, of course, be dictated by practical considerations rather than theoretical. The terrain in the St. Louis area is relatively homogeneous for hundreds of kilometers. The major restriction in extending the network is the location of cities and towns with their own emission sources. It will be impossible to track St. Louis pollutants with near-surface measurements in the vicinity of these sources, and the airborne tracking of elevated pollutants will be made more difficult.

Table XI-2 presents a survey of the population and locations of the major cities and towns within a 100-km radius of the Gateway Arch. As a working hypothesis, it has been assumed that locations of emissions sources and population centers coincide. With the exception of four relatively small towns, all population centers are within 50 km of the Arch. It is particularly noteworthy that the area beyond 35 to 50 km is devoid of significant, secondary emission cores. Table XI-3 lists the principal cities and towns between 100 and approximately 200 km of the Arch; also given are the range, bearing, and population. It will be noted that for the important S-SE windflow cases (with their relatively low ventilation factors and subsequent high pollution potential), Hannibal, Quincy, and Jacksonville lie directly downwind and between 16 and 67 km of a 100-km grid. Under NW flow, the industrial area of Cape Girardeau, Carbondale, Murphysboro, Marion, Herrin, and West Frankfort is 13 to 54 km from the grid perimeter. And for SW flow, Springfield is within 29 km and Decator 60 km.

In summary, we may conclude that the major emissions sources are concentrated within a 35-km radius of the Arch and that a monitoring network (Class A stations) of 100 km-radius from the Arch is satisfactory under most conditions. However, for stable atmospheric conditions and large source heights, attention should be directed toward possible extension of the network for, at least, those wind directions corresponding to low ventilation factors (stable conditions).

Table XI-2

MAJOR CITIES AND TOWNS WITHIN 100 km OF DOWNTOWN ST. LOUIS; POPULATION GIVEN IN THOUSANDS

Illinois

Alton	46	Collinsville	15
Belleville	40	East St. Louis	82
Cahokia	19	Edwardsville	12
Centreville	14	Granite City	42
* Centralia	14	* Litchfield	7
* Chester	4	* Vandalia	5

Missouri

Berkeley	5	Overland	11
Clayton	16	Pine Lawn	6
Ferguson	22	Richmond Heights	15
Florissant	38	St. Charles	21
Jennings	15	St. Louis	750
Kirkwood	29	Wellston	9
Maplewood	13		

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* Located within 50 to 100 km of downtown St. Louis; others are within 50 km.

Table XI-3

MAJOR AREA CITIES AND TOWNS BEYOND 100 km OF DOWNTOWN ST. LOUIS

City, State	Population (thousands)	Bearing* (Rel)	Range (km)
Benton, Ill.	7		
Cape Girardeau, Mo.	25	SSE	54
Carbondale, Ill.	19	SE x S	13
Murphysboro, Ill.	9		
†Columbia, Mo.	37	WNW	77
Decatur, Ill.	85	NE	60
†Fulton, Mo.	11		
Hannibal, Mo.	20	NNW	48
Jacksonville, Ill.	22	N	16
†Jefferson City, Mo.	28	W x S	64
Marion, Ill.	13	SE	29
Herrin, Ill.	9		
W. Frankfort, Ill.	9		
†Mexico, Mo.	13		
Mt. Vernon, Ill.	16		
Quincy, Ill.	45	NW	67
Salem, Ill.	6		
Springfield, Ill.	87	NE	29

---

* Bearings are given for major, nearby cities relative to downtown St. Louis; range is that beyond 100 km; population is given in thousands.

† Cities outside of proposed network orientation.

Network Orientation

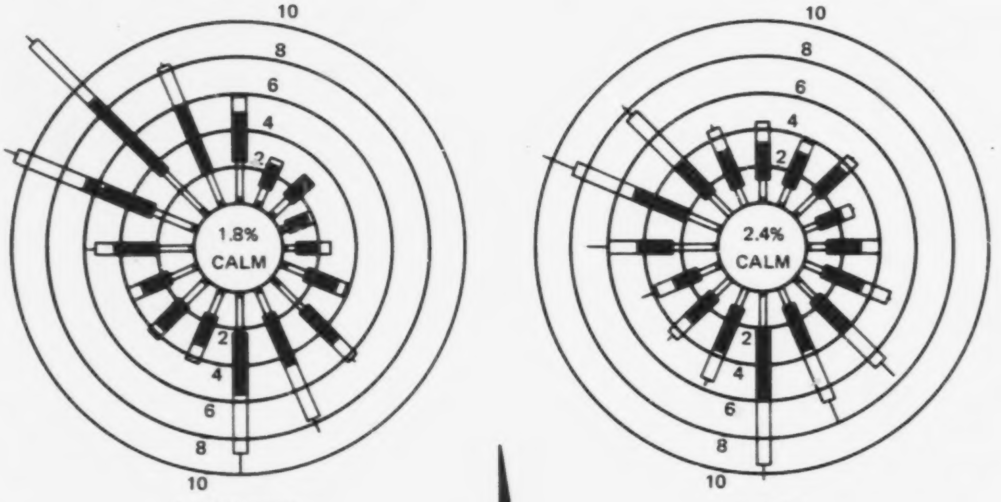
It will be advantageous to consider possible deviations from a uniform circular network design and, also, the limitations which may be imposed on potential modifications. The first item to consider is whether the grid should encompass a circular region or be skewed or elongated in some fashion--perhaps according to the nature of the prevailing winds.

Figure XI-8 is a series of four monthly surface wind roses (for all hours of the day) recorded at Lambert Airport in St. Louis for the years 1951 through 1960. It will be seen that the distribution is not symmetrical but shows a preference for southerly and northwesterly winds. The distribution is sufficiently skewed that a modified grid design based on climatological data may more adequately monitor dispersion processes in the St. Louis area.

To depict in greater detail the annual distribution of surface wind direction, Figure XI-8 (a-d) is combined in Figure XI-9. The prevailing bidirectional nature of the flow stands out clearly with 37 percent of all winds from 180 ± 56^{o} and 24 percent from 315 ± 34^{o}. However, in biasing the location of monitoring stations according to wind direction, an effective transport wind representative of conditions throughout the entire mixing layer must be considered; the surface wind may not be a good indicator--especially under stable conditions (of prime interest to the study) when significant veering occurs near the surface.

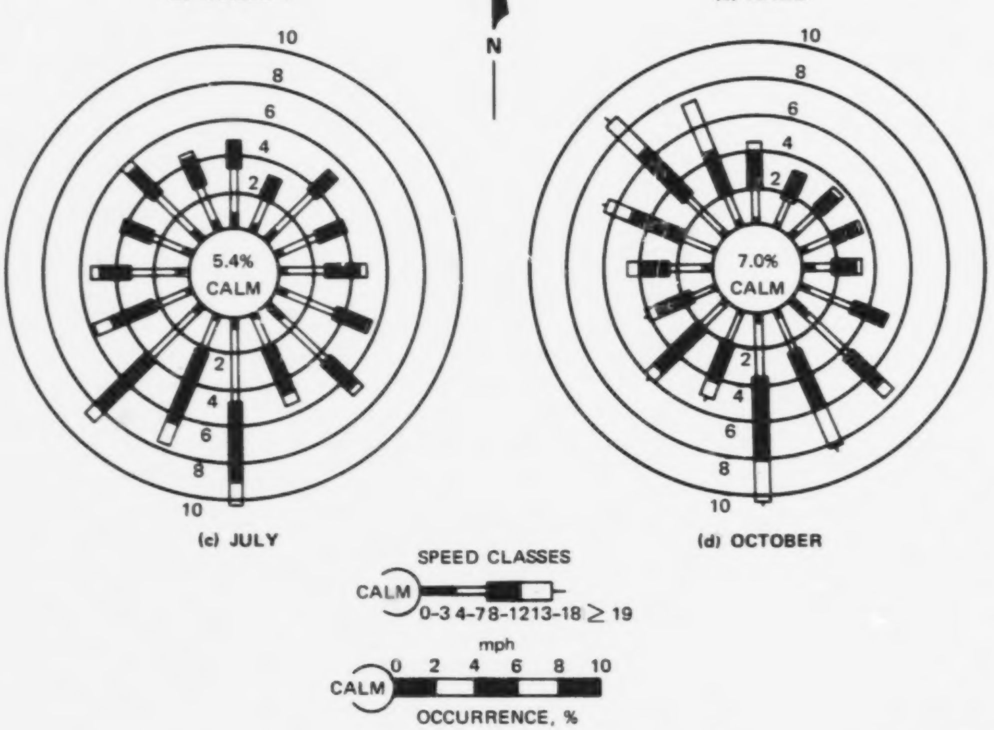
Figures XI-10 and -11 illustrate the frequency of occurrence of winds at 350 m at Lambert Field for four months (January, April, July, and October) over the period 1951-59 during daytime and nighttime periods, respectively. The prevailing winds at this height are more regularly concentrated in a sector from about 180^{o} west through 315^{o}. A more meaningful approximation of the effective transport wind direction can be obtained by considering the direction at some height above the surface in order to describe realistically the manner in which a diffusing "cloud"--ranging in height up to perhaps 1500 m--is transported, as well as to minimize possible directional anomalies in the microscale (surface) observations.

Meteorological data of the type required for a more objective assessment of potential air pollution conditions are now being obtained in St. Louis at the Environmental Meteorological Sounding Unit (EMSU) of the National Weather Service. The EMSU station collects low-level, slow-ascent radiosonde data during the early morning and midday periods at the Gateway Arch. The objective of the program is to provide high resolution data in the lower atmosphere (surface to approximately 3000 m)



(a) JANUARY

(b) APRIL



(c) JULY

(d) OCTOBER

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FIGURE XI-8 SURFACE WIND ROSES FOR LAMBERT FIELD, ST. LOUIS 1951-1960

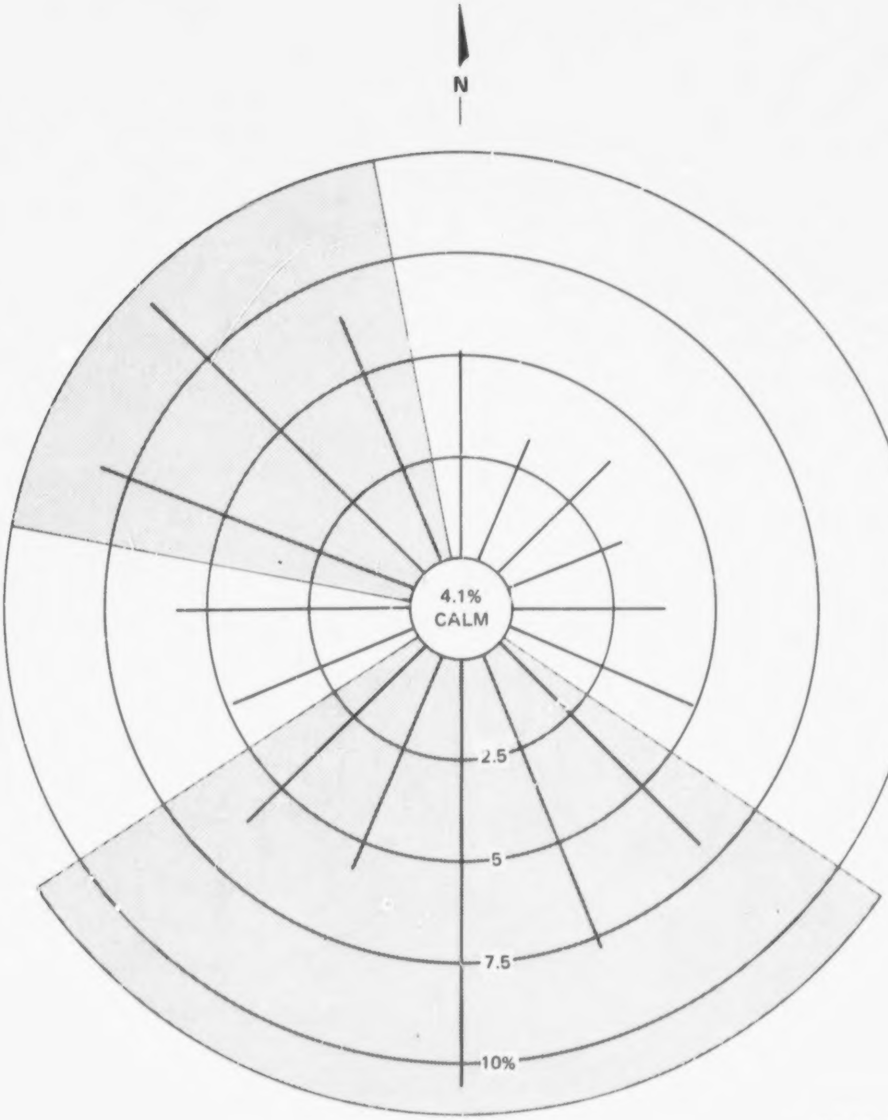

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FIGURE XI-9 COMBINED WIND ROSES: JANUARY, APRIL, JULY, OCTOBER, LAMBERT FIELD, ST. LOUIS, SURFACE OBSERVATIONS, 1951-1960

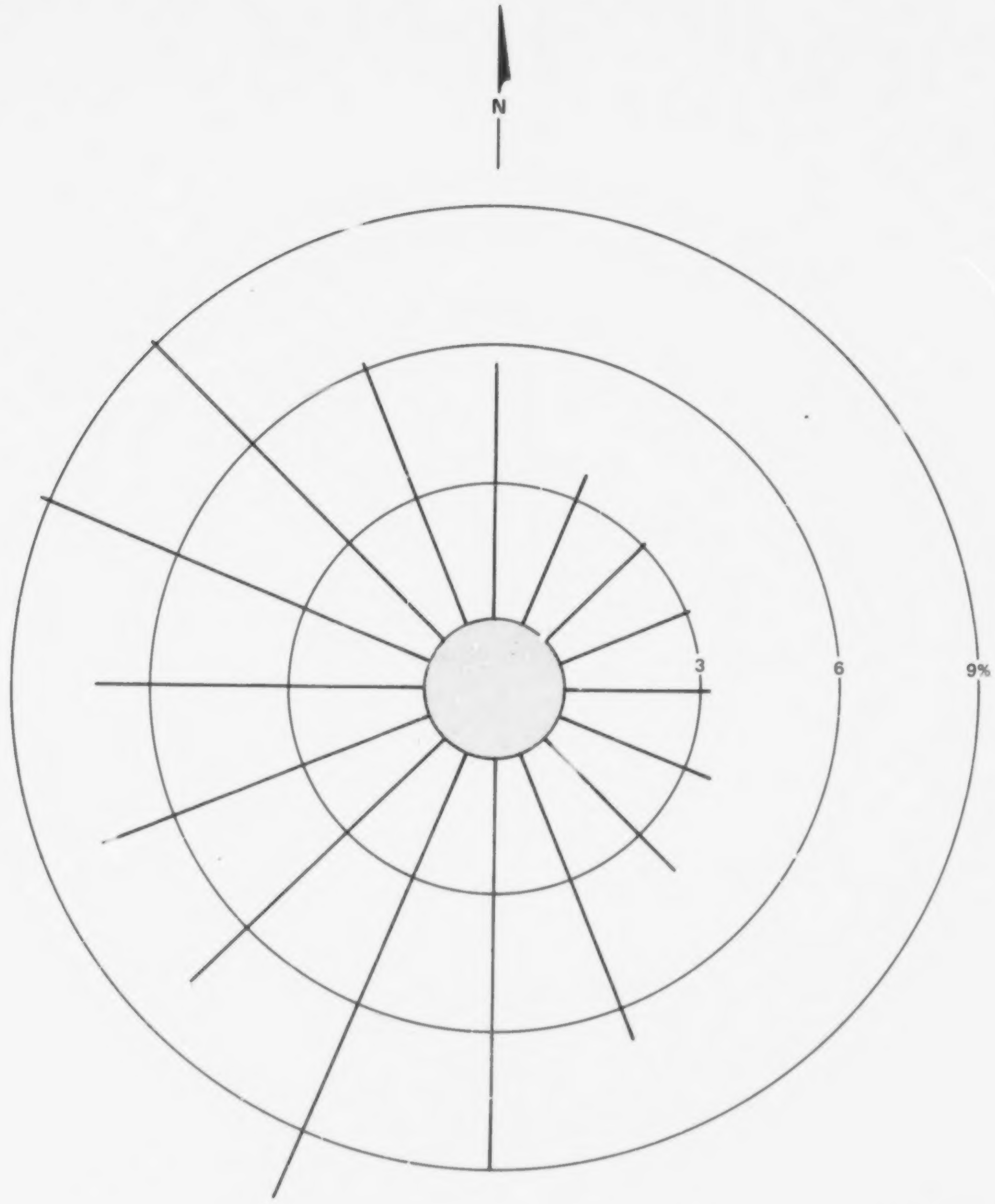

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FIGURE XI-10 WIND ROSE — 1,100 FT, LAMBERT FIELD, ST. LOUIS, DAYTIME OBSERVATIONS, 1951-1959

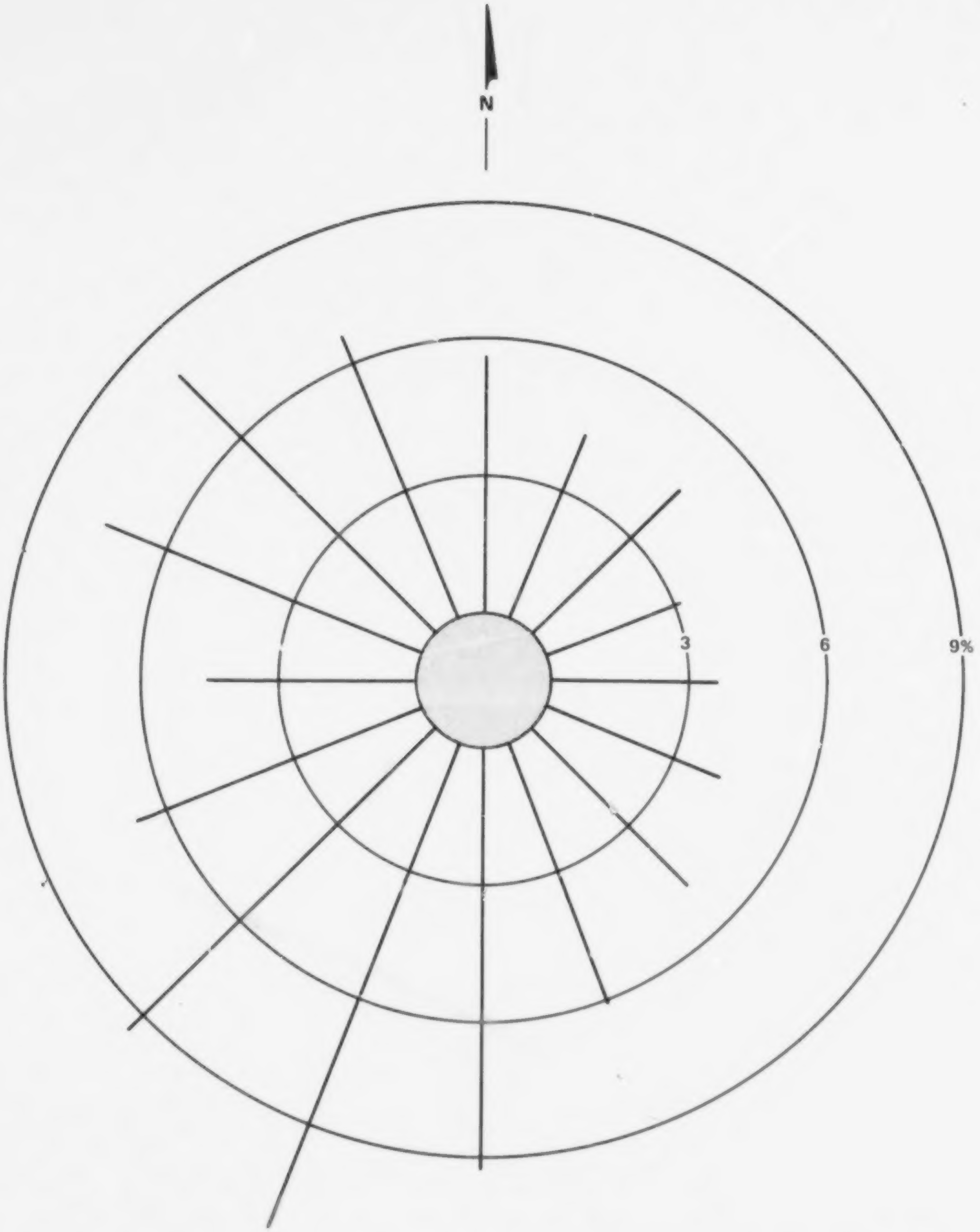

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FIGURE XI-11 WIND ROSE — 1,100 FT, LAMBERT FIELD, ST. LOUIS, NIGHTTIME OBSERVATIONS, 1951-1959

for the evaluation of the ventilation or dilution capability of the boundary layer. Unfortunately, the tracking is done by single theodolite and the accuracy of the results is sometimes questionable, as discussed in the section (Chapter III) on upper air sounding systems. (In fact, it is this limitation that has prompted the recommendation of a system such as METRAC to supplement as well as replace the EMSU program.) In spite of this problem, the data are more useful than any routinely available. The St. Louis EMSU has been in operation less than three years--too short a period for strict climatological averages, yet long enough to provide valuable insight into the problems of assessment of the transport wind and urban mixing depth.

Mr. Donald Wuerch, who is in charge of the St. Louis operation, has kindly provided data for a two-year period on the distribution of ventilation as a function of the transport wind direction and time of day. The transport wind is defined as the mean vector wind over the depth of the mixing layer, and the ventilation (or dilution) factor is the product of the transport wind speed and the mixing layer depth. These data are presented in Figure XI-12 as a ventilation wind rose for both observational periods and are stratified (in azimuth) by the transport wind direction (10^o increments). The length of the radial spurs indicates the frequency of occurrence (as a percentage); the value at the tip of each spur is the ventilation factor (sq m/sec) for each wind direction interval. Figures XI-13 and -14 show the same information for the morning and noon periods, respectively, but over 30^o intervals. The data indicate that for the morning period, 37 percent of the winds are from the quadrant centered on 210° and the associated ventilation factors are extremely small (on the order of 2.1×10^3 m^2/sec). During the midday period, low ventilation factors ($\sim 4.5 \times 10^3$ m^2/sec) are associated with winds from 120°, but these occur relatively infrequently (14 percent). On the other hand, the 210° quadrant shows moderately high midday ventilation (9.2×10^3 m^2/sec) occurring quite often (36 percent).

The orientation of stations in the air monitoring network should, in part, reflect the asymmetry in the mean annual distribution of wind direction in the St. Louis area. This arrangement will restrict the area in which the stations will be deployed, thereby actively increasing the station density. The network may be broken into three primary segments:

(1) A central core where most of the emissions sources and population centers are located. Station spacing will be relatively dense and--in the absence of a systematic pattern of source locations--uniform. Preliminary results indicate this score will be contained with a 35-km radius of the Arch.

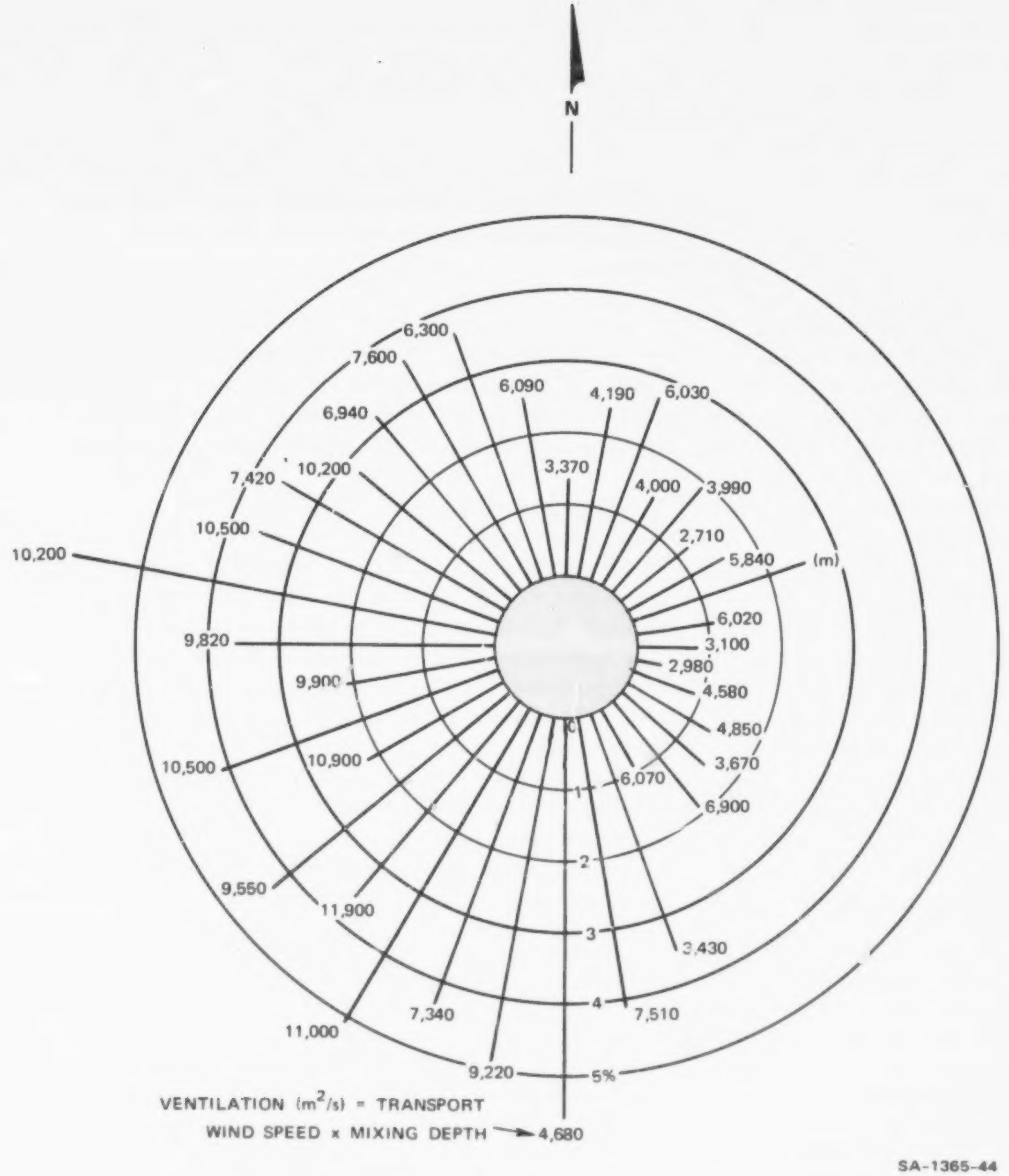

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FIGURE XI-12 VENTILATION WIND ROSE ST. LOUIS EMSU DATA, MAY 1969 - APRIL 1971

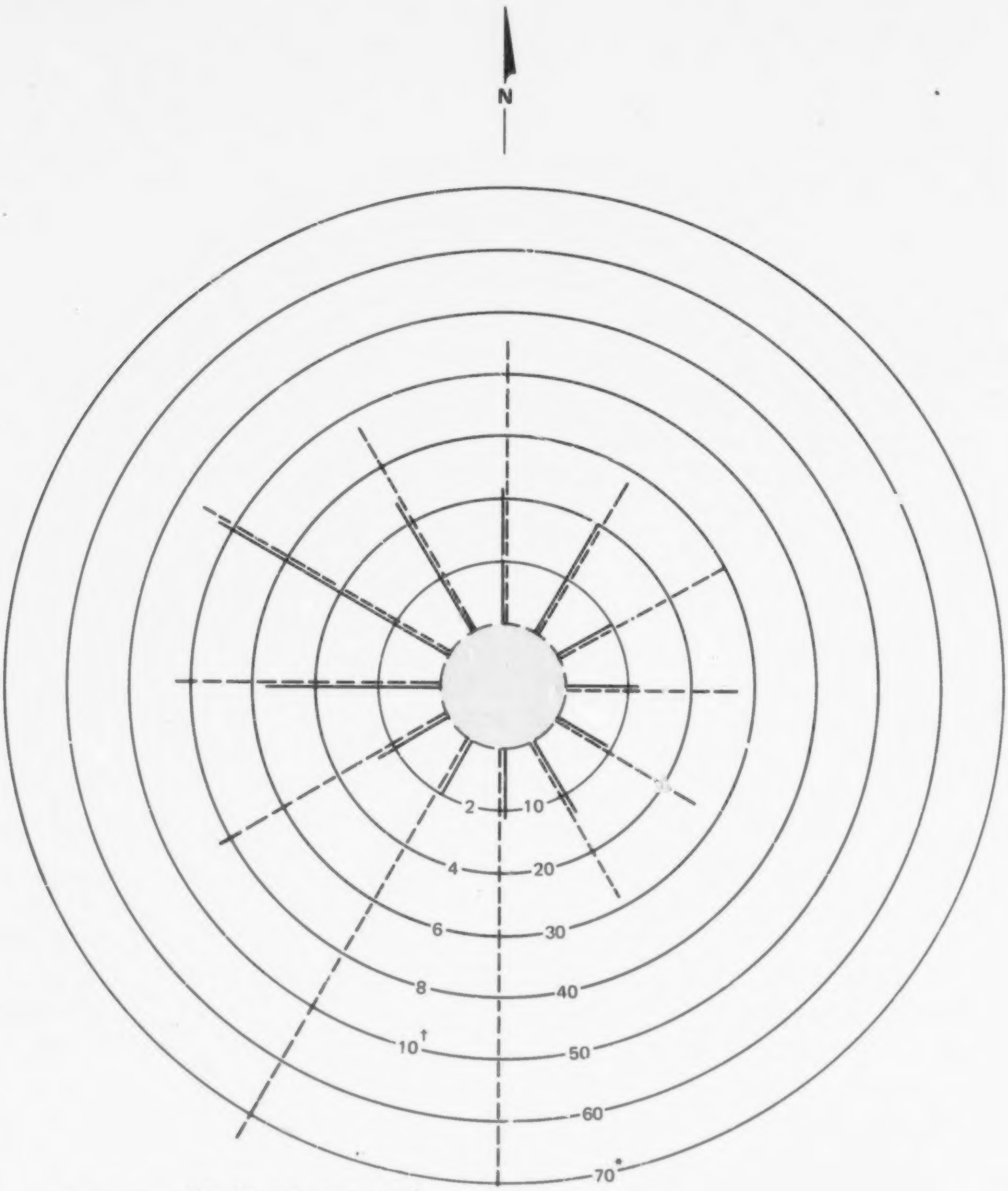

FIGURE XI-13 VENTILATION WIND ROSE, ST. LOUIS EMSU DATA, MORNING SOUNDINGS, MAY, 1969-APRIL, 1971

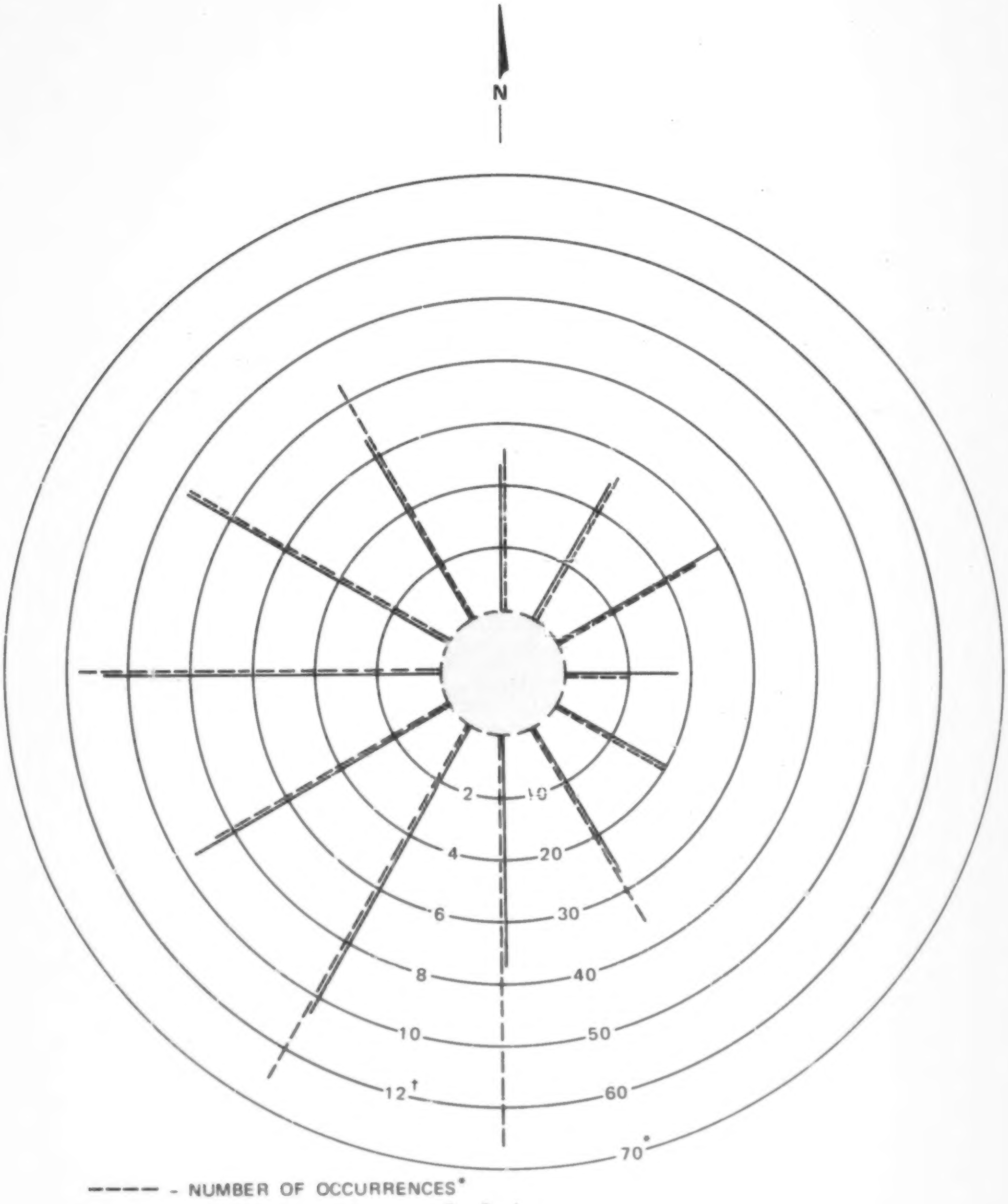

FIGURE XI-14 VENTILATION WIND ROSE, ST. LOUIS EMSU DATA, MIDDAY SOUNDINGS, MAY 1969-APRIL 1971

(2) An outer perimeter encircling the inner core and extending to a radius of about 100 km. Azimuthal station spacing will be uniform while radial spacing should reflect the expected concentration distribution. Station density will be less than that of the inner core.

(3) An augmented sector within the outer perimeter. Based on the need for more detailed measurements under poor ventilation conditions, the northeast quadrant should be supplemented with additional stations. Although it would be desirable to expand the range of measurements in this direction, the locations of the cities of Springfield, Jacksonville, Hannibal, and Decatur limit the maximum useful range to about 125 km.

Characteristics of Stations

It will be noted from the discussions on station design that three distinct classes of station are recommended: Class A--permanent station for the routine acquisition of meteorological and air quality profile data; Class B--semipermanent station for air quality and meteorological data at a single level; Class C--transportable, trailer station to be used for special studies of meteorology and/or air quality. This section provides a reasonable outline of the number of stations that can be anticipated as well as their deployment. Specific details of recommended meteorological instrumentation will follow in the next section.

In locating a fixed-point (or profile) monitoring station, it is hoped that the conditions measured at that location will be representative of the average conditions over a larger area. Upon acceptance of this premise, inverse logic dictates that the station density must be greatest in regions where air quality and/or meteorological conditions are expected to vary most rapidly in space, and station spacing may safely be increased in "flat regions." Figures XI-4 through -7 graphically illustrate how, in principle, these concepts may be applied to the St. Louis region. Furthermore, the limitations imposed by emissions cores surrounding the St. Louis metropolitan area restrict the extent of the study region to something on the order of a 100-km radius from downtown St. Louis. In the specification of the total number of stations that will be required to monitor adequately atmospheric conditions over the region, cost will be a constraining factor. However, the network should comprise the minimum number of stations required to monitor atmospheric conditions on a scale compatible with the evaluation of the more sophisticated air pollution models. From a practical standpoint, the choice cannot be made with the fixed stations alone as the number required would be astronomical ($\sim 3 \times 10^4$). A reasonable compromise is the judicious placement of a moderate number of fixed stations to monitor the larger-scale features routinely, while utilizing the transportable station network to collect data on the fine scale as it may be required. Many of these requirements have been summarized in Chapter III.

The spacing that is proposed between the Class A stations is on the order of 40 km or an order of magnitude less than the synoptic scale network over the contiguous United States. Therefore, a series of nine of these stations is recommended for deployment in a box pattern centered at the Arch, while an additional eight may be uniformly distributed along the 100-km radius. The mean characteristic spacing among the outer stations is increased to about 60 km, but the increase is justified in view of the homogeneous topographic and emissions fields in this outer perimeter. The proposed A-station distribution is depicted in Figure XI-15. It will be noted that two types of Class A stations are shown: types A_1 and A_2. Specific differences are given in the following section; the basic or essential difference is that the A_2 type collects information on the structure of the surface layer (i.e., absolute values and gradients of items such as wind, temperature, humidity, and pollutants) while the A_1 type additionally obtains data on the forcing parameters; namely, the surface energy budget and the mesoscale horizontal pressure field. In view of the relatively small additional cost of the A_1 station, it might be desirable to outfit all A-stations in this manner; what has been proposed, however, is an adequate minimum.

While the Class A stations are designed to provide information on lower atmospheric dynamics, thermodynamics, and pollutant fluxes, the Class B stations will provide higher spatial resolution meteorological and air quality data for kinematic analyses. The objective is the study of the response of the atmosphere (in the form of, say, isotach, isotherm, and pollutant isopleth distributions) to the atmospheric forces and emissions sources. The Class B stations may be considered to be fixed, although they have been designed to permit relocation on an infrequent basis. When reference is again made to Figures XI-4 to -7, it follows that a significant number of these stations should occupy the region of maximum emissions. A suggested grid of B-type stations is depicted in Figure XI-16. Twenty-four stations are located in a uniform, square array within 35 km of the Arch. Initial tests using the transportable Class C stations should probably be made first in order to solve first-order siting problems. An additional number of B-type stations (perhaps eight) should be located in the downwind "poor ventilation" sector--the NE quadrant--discussed earlier in this chapter for the routine,

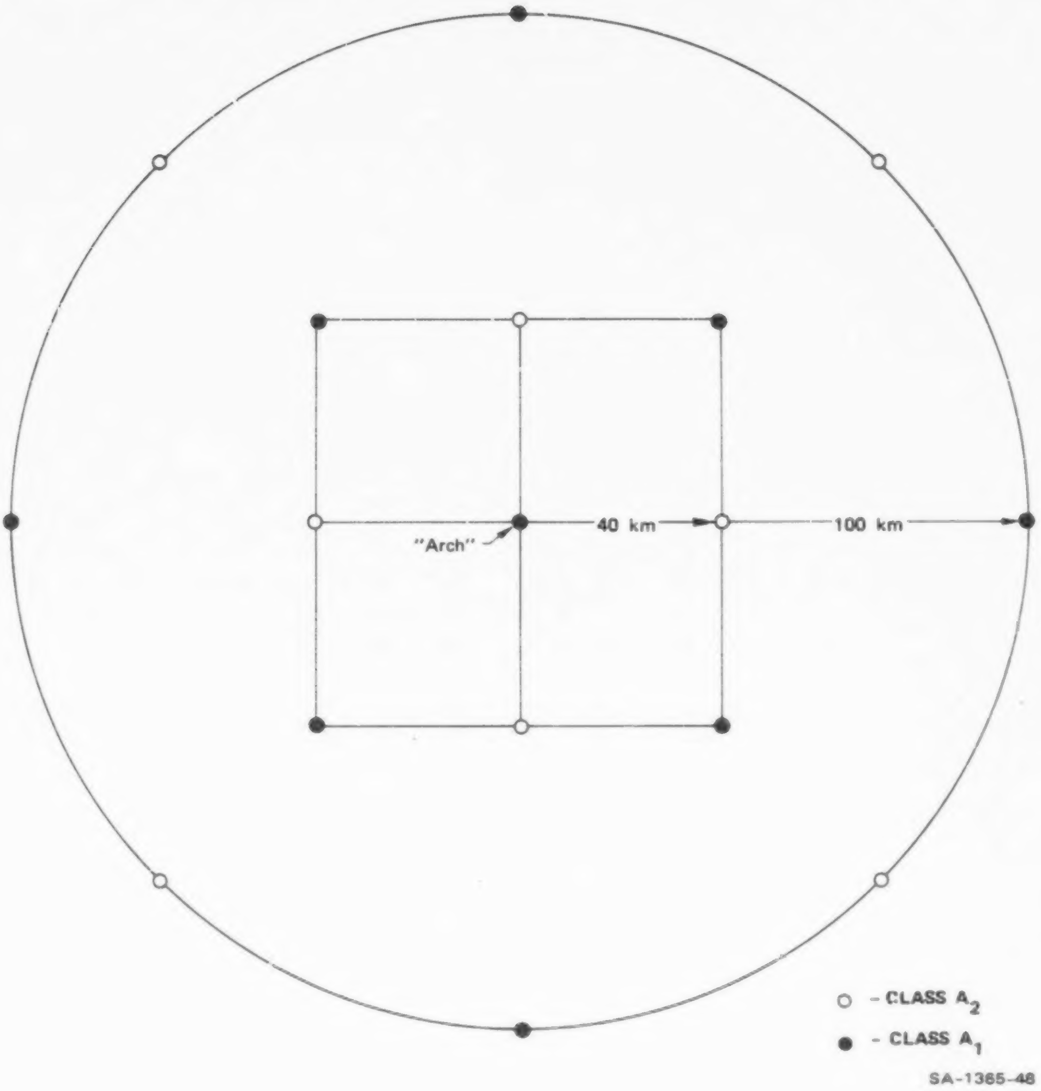

FIGURE XI-15 PROPOSED DISTRIBUTION OF CLASS A STATIONS

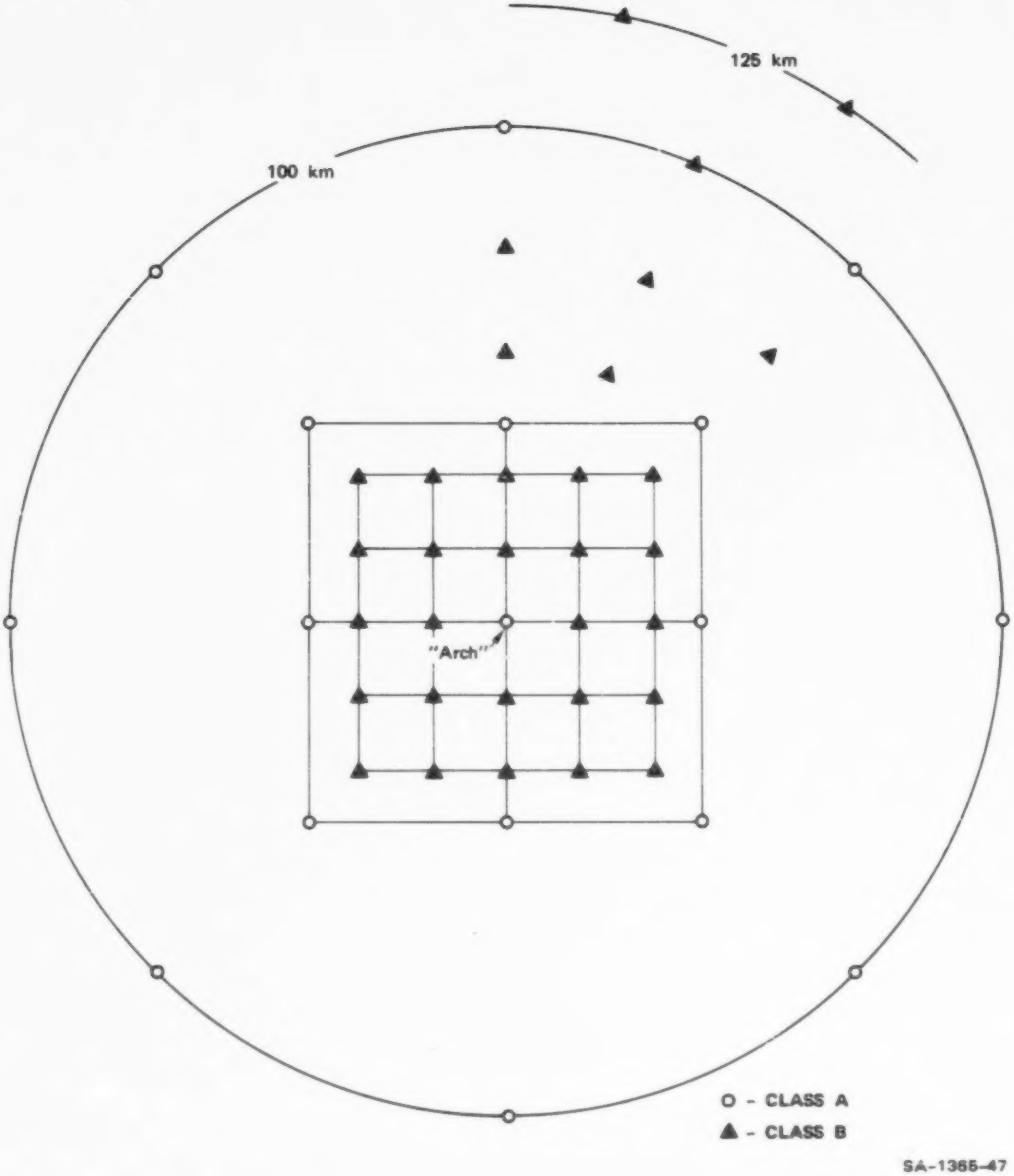

FIGURE XI-16 PROPOSED DISTRIBUTION OF CLASS B STATIONS, SHOWING ALSO THE LOCATION OF CLASS A STATIONS

detailed measurement of air quality at medium-to-long ranges under atmospheric conditions that retard dilution. These are also pictured in Figure XI-16.

The Class C stations provide a wealth of flexibility to both the meteorological and air quality programs. They will be used in a large number of specific and special research tasks. They also give the basic (fixed) system flexibility when they are used to supplement routine observational network. Such flexibility may be required by unique atmospheric conditions or as a result of gaps in the fixed network. The potential of these stations lies in their mobility, adaptability (almost any type or number of observations can be made), and compatibility (the data format is identical to that of the fixed network). The absolute number of C stations that will be required will most likely evolve as the program progresses--an initial estimate would be 16 and a likely projection 25.

In summary, the following number of stations is recommended: Class A_1, 9; Class A_2, 8; Class B, 32; and Class C, 16 to 25.

Meteorological Instrumentation

The meteorological data that are to be obtained under the RAPS program must serve to further the description and understanding of atmospheric processes, and in so doing they will specifically be utilized for input to the various air pollution models as well as for the thorough evaluation of the meteorological aspects of these models. As in the evaluation of station number, a reasonable compromise must be found amongst the requirements of instrumentation, field effort, data processing, and analysis.

In evaluating the representativeness of measurements made at a fixed point or points on a vertical tower, it should be kept in mind that each element of surface structure produces an individual disturbance to the air flow; however, it is the statistical effect of all such disturbances that is important for the study of representative profile structure in micrometeorology. The specific location of a meteorological tower and the height to which it extends must be governed by this principle. As a rule of thumb, the lowest level at which the wind should be measured should be above the tops of the characteristic roughness elements of the area, while the maximum level will be described by the thickness of the internal boundary layer that develops upon a change in characteristic surface roughness. As a rule of thumb, the maximum height of measurement should be less than 2% of the wind fetch that is characteristic of the area while the minimum height should be five times greater than the characteristic height of roughness elements. In the latter case, when reference is made to a forested region, the factor of five will apply to variations in the canopy height and the measurement height itself will be defined above the mean maximum height of the canopy.

In consideration of the number of levels required to be instrumented, the computation of a single measure of mean profile curvature requires data from three levels. Uncertainties in the representativeness or in the determination of the parameters at the various heights will increase the minimum number of levels to four. When vertical gradients and curvature characteristics are to be studied as functions of height, the number of instrument levels should be increased to five or more. When these items are considered with reference to the objectives of RAPS, it will be seen that a minimum number of levels for measurement at each tower will be three, although four would be preferable. It is imperative that both the mean and fluctuations of the u and v components be measured, as well as the fluctuating vertical wind component and possibly also its mean value. Fifteen-minute averages of the mean and variance of the horizontal and vertical wind speed and direction (vector average) should be resolved. Results of micrometeorological studies (such as the 1967 Cooperative Field Experiment at Davis, California) have indicated the occurrence of mean vertical motions persisting over periods of several hours near the surface boundary. The effect on the transport and diffusion processes may therefore be significant and should be examined systematically throughout the study region. With regard to the measurement of the vertical wind, it is perhaps unnecessary that the measurements be made at all three heights--rather a single measurement at the uppermost level may be sufficient. In view of this, estimates for the cost of such instrumentation will be given in the form of two alternate schemes using instrumentation manufactured by the R. M. Young Company as typical price standards.

The wind instrumentation will thus provide data on the mean and variance of the three wind components and also aid in the evaluation of a near-surface value of the eddy diffusivity; these parameters are of direct interest to meteorological dispersion models. The aerodynamic roughness length can also be computed and used to evaluate empirical algorithms that estimate this parameter. Of course, the wind profile is also necessary for the computation of the gradient Richardson number. Additionally, the wind sensors will provide data compatible with commonly available surface wind observations and will serve to evaluate the representativeness of single observations (e.g., airport winds) for use as input in diffusion models (as is the current fashion). Results will very likely illustrate the extreme variability of measurements at the lower heights over the region due to the strong influence of surface discontinuities and the surface aerodynamic roughness in the immediate vicinity of the sensor. Similarly, the upper observations should better represent the features of the flow on a scale compatible with the horizontal distance between stations.

An effect of urban structures will be to decrease the horizontal length scale over which a wind measurement may be considered representative. Similarly, there may also be a need to increase the height to which measurements are made in these built-up areas. Such need may arise if the aerodynamic roughness and zero plane displacement at the station are of the same order of magnitude as the height of the observation. This condition most likely exists in the urban core, and the basic tower network may need to be supplemented by one or several tall towers, in addition to the balloon observations.

Measurements of air temperature should be made at least at the same three heights as the wind measurements and preferably at four levels, with the addition of a near-surface temperature measurement. The temperature sensors must be housed in a temperature radiation shield to prevent measurement errors resulting from the absorption of short-wave radiation with subsequent element heating. The sampling period should be the same as that for the winds (15 minutes). Estimates of variance do not seem essential and the sampling frequency may be reduced. The temperature data are to be used for the computation of the gradient Richardson number (stability index) and the atmospheric sensible heat flux, as well as in the mapping of horizontal temperature gradients for the study of such phenomena as the urban heat island and the thermal wind.

Humidity measurements should be made at the same levels as temperature and at a similar frequency. Moisture data are to be used in the computation of the flux of latent heat, in the study of urban effects on the moisture budget, and for the study of aerosol formation.

Other measurements that need to be made for the study of the surface energy budget as well as other mesoscale meteorological features include: (1) solar radiation, (2) terrestrial radiation, (3) pressure, and (4) precipitation. It may also be desirable to make subsurface temperature profile measurements for the computation of the subsurface sensible heat flux. However, in view of lateral surface and subsurface variations, representative sites may not be readily obtained. These measurements may therefore be made on a special-task basis; routine estimates of the soil heat flux can alternatively be made from an energy budget technique by analyzing the surface temperature response to the solar forcing function.

The types of instruments that are recommended and the class of station where they will be deployed are summarized in the following discussion.

Trade names are indicated only for costing purposes and no specific recommendations are intended; prices are approximate values.

Wind System - Option A

Gill UVW anemometer (R. M. Young,* Model 27003)	$700.00 each
Indicator-translator (Model 27302)	200.00 each
Spare propellers (Model 27108)	20.00 each

Total (Class A--3 levels) = $2880

Total (Class B or C--1 level) = $960

Wind System - Option B

Gill propeller-vane (R. M. Young, Model 35002)	360.00 each
Spare propeller (Model 21180)	18.00 each
Spare tail (Model 35050)	12.00 each
Translator (Model 35402)	260.00 each
Indicator (Model 35602)	90.00 each
Gill propeller anemometer (Model 27101)	150.00 each
Spare propeller (Model 27108)	20.00 each
Indicator-translator (Model 27170)	110.00 each

Total (Class A--3 UV, 1 W systems) = $2460

Total (Class B or C--1 UV system) = 740

Wind System - Additional Equipment

Calibration unit (R. M. Young, Model 27230)	$100.00 each
Mounting booms (estimated)	50.00 each

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* R. M. Young Company, 2801 Aero-Park Drive, Traverse City, Michigan 49684

Temperature System

	Per Level
Gill aspirated radiation shield (R. M. Young)	$250.00
Rosemount* temperature sensor (Model 104)	65.00
Rosemount differential temp bridge (Model 400D)	65.00
Rosemount absolute temp bridge (Model 400A)	90.00

	Per System
Rosemount bridge chassis (1 absolute, 3 diff, No. 421-BX)	$360.00

Class A Station Temperature System Costs

	Option A	Option B
	(1) 4 levels:	(2) 3 levels
Shields	$1000	$750
Sensors	260	195
Bridges	285	220
Chassis	360	360
Total	$1905	$1525

Additional equipment:

Rosemount (2501-4-A10-SC64) digital temperature indicator	$ 735
Rosemount calibration baths	1370-4675

Class B or C Station Temperature Costs

Shield	$250
Sensor	65
Bridge	90
Chassis	360
Total	$765

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* Rosemount Engineering Company, P.O. Box 35129, Minneapolis, Minnesota 55435.

Class A(1) Supplemental Meteorological Instrumentation

1.	Eppley precision spectral pyranometer (2)	$990 each	(SA)*
	0.285 to 2.800 μ		
	5 mV/ly/min		
	Impedance 300 Ω		
	Temp compensation ±1% -20/+40°C		
	Time constant 1 sec		
2.	Pyranometer filters (optional)	$150 each	(SA)
	GG 14 > 0.500 μ		
	OG 1 > 0.530 μ		
	RG 2 > 0.630 μ		
	RG 8 > 0.700 μ		
3.	Barometric pressure transducer	$385	(SA)
	NiSpan C diaphragm		
	Output ≤ 1000 Ω (3 k Ω optional)		
	Range (1) 27.-31.5 in. Hg		
	(2) 28.-32 in. hg		
	Linearity ± 0.3%		
	Sensitivity 0.2% (0.12% optional) [0.27-0.16 mb]		
	Hysteresis ≤ 0.2%		
	Repeatability ≤ 0.2%		
	Temperature operating range - 30/180°F		
	10-point calibration		
4.	Pressure transducer converter	$160	(SA)
	Optional for item 3		
	0-10 mV output (0-100 mV, 0-10 V optional)		
5.	Mercurial barometer (reference)		
	Accuracy 0.1 mm Hg (~0.14 mb)	$190	(SA)
		145	(WM)†
6.	Thermal radiometer (2)	$850 each	(SA)
	Temperature compensation ±1%, -20/+160°F		
	Sensitivity 2.5 mV/ly/min		
	Response time (95%) 12 sec		

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* Science Associates, Inc., 230 Nassau Street, Princeton, New Jersey 08540

† WeatherMeasure Corporation, P. O. Box 41257, Sacramento, California 95841

7.	Dew point hygrometer, Cambridge Systems* Model 992 A (Std)	$2995
	-40 to +80°F dew point range	
	120° dew point depression	
	Accuracy ±1°F (nominal)	
	Platinum element accuracy ± 0.5°F	
	Maximum response 4°F/sec	
	Flow rate 0.5 to 5 CFH	
	Pressure range 0 to 20 psia	
	Instrument operating range 40 to 120°F	
	Sensor temperature range -60 to 200°F	
	Mounting 19-in. rack	
	Cabinet heater (to 120°F)	200
	Optional:	
	Platinum resistance thermometer and output:	
	(a) 100 Ω	295
	(b) 0 to 50 mV dc	490
	(c) 0 to 5 V dc	1090
	Pressure gage--optional	uncertain
	Filters	
	Switching	
	Tubing	
8.	Tipping bucket rain-snow gage	
	Sensitivity 0.01 in.	
	Accuracy 0.5% at 0.5 in./hr	
	Heat control: thermostat 0 to 35°C	$345
	Power: 500 watts	
	Output: mercury switch; discrete event/0.01 in. precip.	
	Alternates:	
	MRI gage (105 watt heater)†	$370
	MRI gage (propane heater)	$525
	Windshield for precipitation gage, options:	$ 89 (SA)
		75 (WM)
		85 (WM)

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* Cambridge Systems, EG&G, Incorporated, 151 Bear Hill Road, Waltham, Massachusetts 02154

† Meteorology Research, Incorporated, 464 W. Woodbury Road, Altadena, California 91001

Chapter XII

AIR QUALITY SAMPLING

Introduction

Data gathering on both a routine and a special basis will be a fundamental activity carried out in the program of the RAPS. The data will include detailed information on both the meteorological and air quality conditions of the atmosphere throughout the region. Facilities will be provided so that these input data can be obtained both at ground level and at least to heights comparable with the surface mixing layer.

This discussion will consider the types of observations to be obtained for the RAPS. Suggestions will also be made covering network design in terms of station input capability and station locations. This discussion will be organized on the basis of three types of surface stations having generally different purposes within the network and one upper air measurement facility.

Permanent Network Monitoring Stations for Pollutants

Three types of monitoring stations will be used to measure pollutant concentrations and meteorological parameters during the course of the RAPS. The stations, designated Class A, Class B, and Class C, will fulfill somewhat different functions in the monitoring network. The Class A ground level monitoring stations will form the basic network for the observation of both meteorological and air quality data throughout the RAPS area. These station sites will be occupied for the duration of the program and the observed data will be continually transmitted to a central control facility for monitoring and subsequent processing. For the purpose of initial estimates, a total of 17 locations is suggested for these Class A stations. The Class A stations associated with a 30-meter meteorological tower will obtain measurements for both meteorological and air quality information at three levels above the ground.

Routine air quality sampling at heights of 3, 10, and 30 meters is suggested. The three-meter height is low enough so that breathing zone concentrations and other essentially ground level measurements can be observed, while at the same time, this height is high enough so that it can be protected from local extraneous activities. The 10-meter sampling height probably represents most nearly a standard sampling height since, except in locations having multistory buildings or tall trees, a 10-meter sampling height will be well exposed to the low level atmosphere. The 10-meter sampling height also conforms to the generally recommended sampling height for ground level meteorological wind measurements and thus should provide a useful standard height for comparing RAPS meteorological measurements with standard synoptic weather observations. From a practical standpoint, a 10-meter sampling height can be obtained for both meteorological and air quality sensors through the use of rather simple structures or portable towers and thus this height could be readily adapted to less permanent stations. These Class A stations should also provide measurements from at least one more upper level and here a height of 30 meters is suggested. This 30-meter height is high enough so that, except in downtown areas, it would be taller than the surface roughness element and would thus provide measurements indicative of conditions in the general transport wind stream. The 30-meter height would also provide an indication of the nature of any vertical stratification, especially that associated with nocturnal inversion conditions. A height of 30 meters can be obtained with commercially available towers that can be maintained without the employment of special riggers or steeplejack personnel. If taller towers can be obtained for use at any of the stations without inordinate costs to the program in terms of either facility or maintenance, they should also be considered and measurements should be extended to the height made available by such special facilities. These special facilities could be one or more of the commercial radio or television broadcasting towers presently situated in the St. Louis area, or they could be special tower installations constructed and loaned to the program by a military or other government agency.

The Class A stations are subdivided into Class A_1 and Class A_2. Nine stations, designated Class A_1, will be equipped with the full complement of meteorological instruments. The remaining eight will be equipped with a limited complement of meteorological instrumentation. The meteorological instrument complements of both Class A_1 and Class A_2 stations are described in detail in Chapter X. Both Class A_1 and A_2 stations will operate with the full complement of pollutant monitors described in detail later in this chapter.

Class A stations will provide the skeleton of the monitoring network. The 17 Class A stations will be located in a geometrical pattern encompassing the St. Louis city center, with the outermost stations located on a 100-km radius from the arch. The locations of the Class A stations and the rationale for their distribution through the area of interest are described in detail in Chapter XI, Meteorological Network and Station

Location. Each Class A station site will require a land area of approximately 1/4 acre to accommodate tower installation, the instrument shelter, compressed gas cylinder storage area, and access for the calibration van. Class A stations located in the city center will require self-supporting towers or access to existing structures of a suitable height for vertical profile measurements. Class A station sites should include perimeter fences of chain link or wire mesh to reduce equipment replacement costs, downtime due to vandalism, and insurance liability.

The instrument shelters at Class A stations must be large enough to house the full complement of pollutant monitors, the data acquisition system, and the local secondary calibration sources with their associated controls. In addition, bench space must be available for installation and operation of additional monitoring instruments required by research programs during the five-year RAPS. The recommended instrument shelter facility will consist of a 15-ft by 24-ft prefabricated insulated building on a concrete slab foundation of 20 ft by 24 ft. The 8-ft by 24-ft apron of the slab floor adjacent to the instrument shelter will be covered to provide shade for compressed gas cylinder storage. Active compressed gas cylinders for calibration, zero gas, and reagents will be plumbed through the wall of the shelter. Three sample inlet lines of TFE Teflon of approximately one in. I.D. enclosed in a protective armor will originate at the 30-meter, 10-meter, and three-meter levels of the meteorological tower and terminate in a manifold within the instrument shelter. A low pressure blower will exhaust the air from the manifolds and keep a constant flow of air through the sample lines. The constant air flow through the sample lines permits equilibration of the atmospheric constituents with sample line surfaces and will reduce the apparent dead volume of the lines. The pollutant monitors have access to sample air from all three tower levels and access to calibration gases. Solenoid-actuated valves would permit programmed access to the sample lines or continuous sampling from a single level sample line. The sample line manifolds will have a common vent to the exhaust blower. Access to calibration gases would be initiated by the calibration controller on a programmed schedule.

At each Class A station a Master Station Controller will control the overall operation of the station. The Master Station Controller will initiate calibration via a calibration controller on a programmed schedule, and will sequentially actuate a solenoid valved system to complete a two-point calibration with zero and span gas. The Master Station Controller will switch pollutant monitors to sample sequentially from all three sample levels. In addition, it will monitor parameters that are critical to operation of the station, such as sample flow rates (where appropriate), gaseous reagent flow rates, temperature of permeation tube baths, and others. A warning system would be employed to initiate a flag to the central computer facility when these parameters did not lie within preset limits.

Data acquisition equipment required for temporary storage of data and read-out of accumulated data upon interrogation by the central computer facility would complete the instrumentation complement. At least one telephone line at each station will be required for data transmission to the central computer facility. The data acquisition equipment is described in detail in the appropriate section of this report.

The instrument shelters must be provided with electrical heating of about 40,000 Btu, and refrigeration cooling of 35,000 Btu capacity. A standard 100-amp residence-type inlet electrical terminal will provide adequate utility power for operation of the Class A shelter. No connection for water or sewer will be required.

Semipermanent Monitoring Station

It is recommended that 32 Class B stations be deployed in the monitoring network. The Class B stations are usually similar in design and function to the Class A stations except that there will be only one sampling inlet at a height of 10 meters, and wind direction and wind speed will be recorded by conventional anemometers instead of the three directional u, v, w techniques. Since sample access from one inlet height is proposed for Class B stations, the instrumentation inlet manifold will be simpler than that of the Class A stations with no switching required between sampling inlets.

A simple 10-meter TV antenna tower could be substituted for the complex and expensive sampling tower used for most of the Class A stations. The instrument complement for the Class B stations would be similar to that of Class A stations, but the rapid response total sulfur monitor and nondispersive infrared CO monitor would be eliminated. The rapid response analyzers are recommended for the Class A stations to provide monitoring of CO and total sulfur concentrations at all three levels within a five-minute interval. The Class B stations are subdivided into Class B_1 and Class B_2. The Class B_1 stations are designated as fixed stations and use the same instrument building and foundation as that recommended for Class A stations. It is recommended that a total of 24 Class B_1 stations could be used in the monitoring network. The Class B_2 stations will utilize an 8-ft X 20-ft shell house trailer to house the instruments. The Class B_2 trailer shelters would not require the slab foundation. A total of eight Class B_2 stations is recommended. Elimination of the meteorological tower would reduce the land area requirements of the Class B site to a plot of 50 ft by 50 ft. Meteorological instrumentation employed at the Class B stations would measure wind speed and direction rather than the wind vector component sensors of the Class A stations. The data-acquisition system for the class B stations would be similar in all respects to the Class A stations without meteorological towers. Again, a function controller would be required to calibrate air quality instruments at selected intervals and to monitor critical instrument parameters and calibration temperatures. The Class B stations should be perimeter fenced with agricultural mesh fencing where feasible. The semi-permanent Class B stations would be considered transportable rather than portable.

The Class C, or portable stations, would be housed in a trailer or van and would be intended for measurements at a discrete site for six months or less. Two types of Class C stations are recommended for the RAPS monitoring network. Class C_1 stations would consist of a small trailer or van with a full meteorological complement and data-acquisition system including a 30-meter tower. The Class C_1 station, though not portable, will be located and operated at more than one site during the RAPS program. No air quality instruments would be used in the Class C_1 stations.

Class C_2 stations are designed to be easily adapted to the specific needs of a wide variety of research programs. The permanently installed equipment in these stations would be limited to the simpler meteorological instruments, a data-acquisition and local recording system, and a sample inlet system to monitor at a 10-meter height. A standard sampling manifold will be provided that can be used by a number of air quality sampling instruments. The bench and/or rack space available for installation of air quality sampling instruments should accommodate four to five instruments. The instrument mounting technique should be compatible, wherever possible, with the concept of monitor installation and check-out at the central facility with the trailer and instrument complement then transported to the selected site.

Although most sites selected for Class C_2 stations will have utility power available, portable power generating systems should be available as an optional power source. The trailers designed to use either a portable power source or utility power should also be equipped with a well-vented liquid propane gas heating system to reduce the power requirements of the portable generator. The power requirements of such a Class C station, including instruments and air conditioning, could probably be supplied by a generator of 5- to 8-kW capacity. Prime movers using liquid propane gas are recommended with full storage capacity to operate the station continuously for one week.

The meteorological sensors installed in each Class C_2 station will include wind direction and wind speed using conventional anemometers and wind vanes, and possibly atmospheric temperature and relative humidity sensors.

The data-acquisition system permanently installed in a Class C_2 station should include all the basic equipment common to both on-board recording and direct data linkage to the central control network. Package assemblies then would complete the conversion to either on-board or remote recording. Any on-board recording should, of course, be compatible with the system used for the rest of the network. Data from on-board recorded tapes must be readily integrated into the network data records.

Class C_2 stations will be located in areas defined by the specific requirements of the experimental programs in which they will be used. In some cases, the needs of several research programs can be realized with one Class C_2 station at a single location. Conversely, any program having more extensive shelter space requirements on a temporary basis could combine two Class C_2 stations at a single location and use the data-acquisition system of one station for data storage or linkage to the central control facility.

Class C_2 stations should also have perimeter agriculture fencing enclosing the site where feasible to avoid unauthorized access.

To provide spatial resolution of the meteorological data acquired from the permanent stations, the 24 Class C_2 stations would be deployed within an area where data augmentation is required. More detailed, spatial resolution of the meteorological data is necessary, for example, for development and validation of atmospheric models describing areas where elements of surface roughness distort or modify circulation patterns.

The C_2 mobile laboratories are also designed to accommodate a limited complement of air quality instruments. The deployment of an array of C_2 trailers containing one or more air quality monitors would provide valuable data to the research programs. These would provide within specific areas finer resolution of pollutant concentrations with respect to distance and surface roughness. For example, the reactive chemistry program could require improved spatial resolution in the studies of the transformation of sulfur dioxide downwind of urban emission sources. In this instance, the number of mobile stations that would be outfitted with sulfur dioxide monitors and the deployment of the stations would be based largely on the incongruities in the data acquired by the fixed monitoring network and on special program needs. Collection of pollutants other than SO_2, such as NO_x, CO, and possibly ozone and particulate material would require deployment of C_2 stations within a specific area of interest to fill in the gaps observed in network concentration rate.

The C_2 trailers may also be outfitted and deployed for specific experiments. Tracer release studies using sulfur hexafluoride would require outfitting with electron capture gas chromatographs. If dye or phosphor tracers are released, then filter collection or other particulate collection schemes would be employed at the individual sites.

It is not possible at this time to predict all pollutants or trace compounds for which the C_2 trailers may be outfitted, except in a general way. The most likely pollutant candidates would be SO_2, NO_x, and CO. The same measurement techniques recommended for the network stations would be recommended for the mobile laboratories. The cost of pollutant monitors for SO_2, NO_x, CO, would be $4000, $5000, and $3000. respectively per trailer. No changes in the data acquisition system would be required. The number of trailers required must be determined on the basis of program needs. Extensive spatial resolution studies could require a minimum of 16 outfitted trailers to a maximum of 24, located at specific sites for one to two months. Less extensive studies may only require 5 to 10 outfitted trailers relocated on a weekly or biweekly basis.

Pollutants To Be Monitored for Establishment of Air Quality

The air quality monitoring equipment that forms the instrument complement of the Class A and Class B stations will measure the following pollutant concentrations in the atmosphere: carbon monoxide, methane, nonmethane hydrocarbons, total hydrocarbons, nitric oxide, total nitrogen oxides, sulfur dioxide, hydrogen sulfide, total sulfur, ozone, and suspended particulate material. National ambient air quality criteria have been issued for all of these pollutants either as a class of compounds, such as hydrocarbons, or as a specific entity which must be distinguishable or definable from other class members commonly found in aerometric surveys. The importance of these pollutants and their relationship to overall air quality has been extensively documented in the technical literature as well as in the formal Air Quality Criteria issued by the Environmental Protection Agency and the U.S. Department of Health, Education and Welfare. A very brief description of these pollutants, their origin, and their significance follows.

Carbon Monoxide

Total emissions of CO exceed those of all other pollutants combined. Incomplete combustion of carbonaceous fuels represents the only significant source of CO on a global basis. The major combustion source is the gasoline engine. A number of geophysical and biological sources are known; however, their contribution to urban atmospheric concentration is not considered to be significant. CO can be used as a tracer pollutant for automotive emissions and will provide data on the dilution of pollutants as a function of source distance.

Methane, Nonmethane Hydrocarbons, and Total Hydrocarbons

Methane occurs as a natural constituent of the unpolluted atmosphere at an approximate concentration of 1.5 ppm. Although CH_4 is a major constituent of automobile exhaust and other combustion gases, its nonreactive role in atmospheric chemistry makes measurement of CH_4 concentration in the atmosphere of secondary concern. The measurement of THC, particularly with the CH_4 component subtracted, is of primary interest in air quality. The measurement of primary emissions of nonmethane HC as well as the secondary HC products formed as the result of chemical reactions in the atmosphere is of extreme interest to the RAPS.

Nitrogen Oxides

Nitric oxide (NO) and nitrogen dioxide (NO_2) are the only significant pollutants of the nitrogen compounds. Their importance as pollutants arises mainly from their participation in photochemical reactions involving reactive organics and sulfur dioxide. NO and significantly less NO_2 are produced as a result of high temperature combustion. Although significant quantities of NO_x are produced from biological sources, most of the NO_x produced from anthropogenic sources originates as NO and is oxidized in the atmosphere to NO_2. In air quality measurements it is important to differentiate the NO component from total NO_x to characterize the photochemical reactions occurring in the atmosphere.

Sulfur Oxides and Hydrogen Sulfide and Total Sulfur

The oxides of sulfur are common atmospheric pollutants that have become one of the major pollution problems of the later 1960s. The oxides of sulfur originate primarily from combustion processes. Solid and liquid fossil fuels contain appreciable amounts of sulfur in the form of organic sulfur-containing compounds and inorganic sulfides. The oxides of sulfur in combustion products are predictable from the sulfur content of the fuel. Insignificant quantities of SO_2 are released to the global atmosphere from natural sources. Conversely, the worldwide distribution of H_2S is primarily the result of natural processes, such as decay of organic matter under anerobic conditions.

Most aerometric surveys have considered that a total sulfur measurement is primarily a measure of SO_2. However, recent data have confirmed that a significant portion of the total atmospheric sulfur may be present as H_2S in areas where coal combustion is minimal. It is recommended that the air quality monitoring instruments of the RAPS differentiate the contribution of H_2S and SO_2 to the total sulfur burden.

Ozone

Photochemical reactions between NO_x and HC produce secondary products classified as oxidants. A major component of these oxidant products is ozone. Other components present as oxidants are nitrogen dioxide and peroxyacyl nitrates. The ozone concentration of the atmosphere is an important indicator of the extent of photochemical processes occurring in the atmosphere.

Suspended Particulate Material

Natural sources of atmospheric aerosols include dust, sea salt particles, and smoke from combustion and volcanoes. In addition, naturally emitted gaseous materials can form aerosols through atmospheric reaction processes. Sulfate aerosols are formed by sulfur compound reactions, nitrate aerosols by nitrogen oxide reactions, ammonium aerosols by ammonia reaction, and photochemical aerosols by atmospheric reaction of natural emanations of terpenes and terpene-type hydrocarbons. Haze, as a result of particulate in the atmosphere, is often the first noticeable phenomenon associated with the development of air pollution in an area. Thus, measurement of particulate and atmospheric turbidity is an important parameter of air quality.

Other Pollutants of Interest Not Measured by Network

Measurements of atmospheric concentration of the pollutants for which Air Quality Criteria have been issued will provide a general index as to air quality within the instrumented region. However, measurement of specific pollutants other than those scheduled for network monitoring can be integrated into the Class A and Class B stations during the program. These stations are designed to expand the instrument complement with only a modest expenditure in expense and effort. The financial responsibility for specific pollutant monitors other than the standard complement and their installation costs should fall within the role of research programs. As an example, if a specific research program requires atmospheric monitoring of beryllium, then clearly the cost of acquiring and analyzing samples should be borne by the research program. Many other research programs may require support from the permanent RAPS staff without the associated costs being borne entirely by the research program. Expanding the capability of network monitors to measure ammonia concentrations can be achieved by modification of the operating procedures of existing network monitors. This type of input data expansion is less clearly definable as being within the role of research programs. The other end of the spectrum is illustrated by the specific requirements for additional pollutant concentration measurements to define the atmospheric chemistry of the region. To define the reactive chemical processes within the area the suspended particulate material should be characterized as to sulfate, nitrate, and chloride content. In addition, the benzene or hexane soluble fraction of the collected particulate must be determined. Atmospheric concentration of peroxyacetyl nitrate, other organic nitrates, oxygenated organics, total aldehydes, and formaldehyde should be defined to unify and improve atmospheric models. Sample collection and specific analysis of these atmospheric constituents do not lend themselves to automated procedures and were not included in the network instrument complement. The atmospheric chemistry measurement requirements are not considered to be within the role of a research program but rather as a separate function within the framework of the RAPS. The details of the sampling procedures and analysis requirements for the atmospheric chemistry phase are described elsewhere in this report.

Pollutant Monitoring Techniques

The types of air quality sampling instruments incorporated into the station instrument complement for a large network must be evaluated based on the specific requirements of the RAPS. The following list of parameters must be considered in the evaluation of commercially available instruments to measure atmospheric pollutants:

- Reliability--a five-year lifetime with minimum downtime
- Suitability to unattended operation

- Accuracy and precision--within state-of-the-art
- Sensitivity--must measure pollutants in rural areas
- Specificity--must be specific or reasonably so
- Stability--minimal zero drift and span drift
- Ease of calibration--frequency and time required to calibrate
- Sample cycle time
- Reponse lag time
- Operating temperature extremes
- Operating humidity range
- Linearity of response
- Instrument noise
- Supplementary reagents or gases required
- Utility services other than power required--water, sewer
- Physical size
- Ease of maintenance--type of construction
- Initial cost of instrument.

These factors and others must be weighed in selecting the most suitable instrumentation for pollution monitoring. Selection or recommendation of specific instruments by vendor is not within the scope of this report; however, recommendations will be made as to the pollutant measurement technique or techniques that are suitable for inclusion in the network instrument complement. A committee within EPA should be formed to select the individual pollutant monitors, by vendor, to comprise the basic instrument complement of the network stations.

Carbon Monoxide, Methane, and Total Hydrocarbon

A single automated gas chromatograph using hydrogen flame detection and an appropriate inlet valving and column system can measure the atmospheric concentration of CO, CH_4, and THC. Nonmethane HC concentrations can be determined by the THC and CH_4 difference. Total HC are commonly measured by direct sample gas insertion into the hydrogen flame detector. The separation of atmospheric constituents by gas chromatography prior to detection in this multipurpose instrument permits specific measurements of CO and CH_4 as well. The measurements of CO, CH_4, and THC are standard with this type of gas chromatographic instrument, but additional HC (ethylene and acetylene) can also be measured if need warrants the additional expense. The measurement sensitivity (1 ppm full scale for CO, CH_4, and THC) is suitable for ambient air monitoring in rural areas. One disadvantage of gas chromatographic measurement techniques is that the measurements are cyclical, with five minutes required for analysis of all three components. The use of the monitor with its five-minute sample cycle at all three levels of the Class A stations would permit only one concentration measurement per level for each 15-minute data interrogation by the central data acquisition system. It is recommended that a supplementary monitor for CO with rapid response be included in the basic instrument complement of each Class A station associated with a meteorological tower. A monitor for atmospheric CO based on the nondispersive infrared (NDIR) technique is recommended to supplement the gas chromatographic CO measurements. The NDIR CO monitor would be sequentially valved to measure all three vertical profile levels in a single five-minute interval. The inherent poorer sensitivity of the NDIR CO instruments (generally 50 ppm full scale) makes this approach attractive only for those towers located in urban or semirural areas where CO concentrations are of such levels that meaningful data can be obtained. The gas chromatographic CO would then be limited to measurement at one level only, that is, 10 meters. The Class A stations without towers and Class B stations would not require the supplementary NDIR CO measurements.

The only other technique for the measurement of CO in the ambient atmosphere is based on mercury replacement with detection of mercury vapor by ultraviolet absorption. Commercial instrumentation employing this technique is not considered as reliable or as specific as either the gas chromatograph or NDIR. Therefore, atmospheric monitors using the mercury replacement technique are not recommended for the basic instrument complement of the network stations.

producing free iodine. The iodine is reduced back to iodide coulometrically, with the required current directly related to pollutant concentration. The technique for NO is similar, except that NO_2 is removed by a scrubber system and the NO oxidized to NO_2 by internally generated ozone. The resultant NO_2 is then measured coulometrically as described. The coulometric analyzer for NO and NO_2 is not as specific as the chemiluminescent technique and may require somewhat more routine maintenance. The response time of the coulometric NO and NO_2 is much slower (10 minutes) than that of the chemiluminescent technique (2 seconds). Although the instrumentation for coulometric NO and NO_2 is nearly identical, the response time prohibits alternating NO and NO_2 measurements on a single instrument. Therefore, two coulometric analyzers would be required in each station instrument complement. The full scale sensitivity of the coulometric analyzer is an order of magnitude lower than that of the chemiluminescent (0.2 ppm coulometric versus 0.02 ppm chemiluminescent).

The membrane-solid electrolyte electrochemical NO_x monitor could also be considered a second-generation technique. This technique was initially developed for stack sampling rather than ambient air monitoring. Early instruments of this type lacked sensitivity to measure the low concentrations of NO and NO_x present in ambient air. Although considerable improvements in this electrochemical scheme have been made, frequent replacement of the sensor module and poor specificity make this unsuitable for inclusion in the instrument complement of the network station.

Another technique for measurement of NO_x is that of ultraviolet absorption using a second-derivative measurement scheme. This third-generation instrument is quite new and as yet unproven in its capability. The measurement technique is very versatile and can be used to monitor sulfur dioxide and ozone, as well as NO and NO_2, The full scale sensitivity of the second-derivative (d^2) spectrometer is 0.12 ppm for NO and 0.8 ppm for NO_2. These specifications indicate that at the current state-of-the-art, the technique is feasible for NO but of marginal sensitivity for ambient monitoring of NO_2. This d^2 spectrometer shows definite promise but, without additional information as to its performance both in the laboratory and in the field, its applicability to the RAPS cannot be assessed. The multicomponent measurement capability of the d^2 spectrometer is of considerable interest and therefore it is recommended that this technique be field evaluated, possibly within a RAPS research program.

The last technique to be discussed for monitoring of NO_x in the atmosphere is that of colorimetric measurement, the basis for the first-generation atmospheric monitors. This scheme has been in use for many years and its inherent problems and limitations are well known. Although the NO-NO_x colorimetric techniques have been continuously improved and modified to meet monitoring requirements dictated by more stringent air quality regulations, the limitations of colorimetric techniques stimulated the development of new second- and third-generation analysis schemes. The problems associated with colorimetric analysis of NO_x are often those of a physical or mechanical nature, failure of pump tubing, unreliable operation after cleaning, and formation of mold. Nonlinear response to different concentrations of NO_2 is also often encountered. Therefore, based on the long history of usage of the colorimetric technique, this monitoring technique for NO_x cannot be recommended.

Recommended Monitors for NO and NO_x

Chemiluminescent Method: subject to evaluation at initiation of RAPS

Coulometric: second choice if chemiluminescent evaluation is negative.

Sulfur Dioxide, Hydrogen Sulfide, Total Sulfur

The first-generation and most commonly used pollutant monitors for sulfur compounds measure only the SO_2 concentrations. The use of instrumentation to monitor only SO_2 in the atmosphere is based on the premise that the emission of sulfur compounds other than SO_2 represents only a small fraction of the total sulfur burden. However, recent surveys have shown that in areas of low coal usage significant concentrations of hydrogen sulfide (H_2S) may be present in the atmosphere. Therefore, it is recommended that second-generation monitors employing techniques that can distinguish the individual contribution of SO_2 and H_2S to the total sulfur burden be employed in the RAPS. The monitoring technique for SO_2 and H_2S is similar in many respects to the technique used for CO, CH_4, and THC. A single automated gas chromatograph using flame photometric detection and an appropriate inlet valving and column system can specifically measure the atmospheric concentrations of SO_2 and H_2S. The automatic gas chromatographic measurement technique has the disadvantage that a sample cycle must be used rather than continuous measurements. A sample cycle of three-minutes' duration is required for measurements of SO_2 and H_2S. The use of this monitor with its three-minute sample cycle for all three levels of Class A stations would permit only one measurement of each level for each five-minute interrogation by the central data-acquisition system. Therefore, it is recommended that a supplementary monitor for total sulfur with rapid response be included in the basic instrument complement of each Class A station associated with a tower for vertical profile measurements. A monitor for atmospheric total sulfur based on a flame photometric measurement technique without separation by chromatography is recommended to supplement the gas chromatographic SO_2 and H_2S measurements. The flame photometric total sulfur instrument would be valved to measure all three vertical profile levels in a single five-minute interval. The gas chromatographic SO_2-H_2S measurement would be limited to only one level--that at 10 meters. The total sulfur monitor using flame photometric detection without separation gives a high degree of specificity for measurement of all sulfur-containing compounds. These techniques are reliable and require little maintenance in unattended operation. The gas chromatograph-flame photometric SO_2 and H_2S technique and the flame photometric total sulfur have been evaluated in both laboratory and field conditions. They are currently recommended as equivalent to the reference method published in the Federal Register.

Another technique for the measurement of SO_2, discussed previously in the section on nitrogen oxides, is that of ultraviolet absorption using a second-derivative measurement. This technique is a third-generation technique that has not been in use sufficiently long to evaluate. The sensitivity to measurement of SO_2 (0.06 ppm full scale) is competitive with that of the flame photometric method. This instrument should be evaluated further, possibly within the role of a research program of the RAPS.

Another second-generation technique for the measurement of SO_2 is that of membrane-solid electrolyte electrochemical measurement. Poor specificity and frequent sensor module replacement make this technique unsuitable for unattended monitoring of ambient concentrations of SO_2.

The last techniques for measurement of SO_2 to be discussed are those of the first-generation SO_2 monitors. These techniques include colorimetric, coulometric, and conductimetric means of sensing the concentration of SO_2 in the atmosphere.

The instruments employing colorimetric analysis, particularly the conventional West-Gaeke scheme, can provide acceptable analyses for SO_2. The pararosaniline colorimetric method has been collaboratively tested and is recognized as valid. The instruments using colorimetric analysis, however, are subject to considerable downtime due to mechanical problems and lengthy calibration procedures.

Coulometric methods of sensing atmospheric SO_2 concentrations are probably the best of these first-generation schemes. The correlation of the observed concentrations of SO_2 by coulometry with respect to the West-Gaeke method is fairly good, and fair reliability under field conditions can be obtained with this instrumentation. However, neither the reliability nor the accuracy of the coulometric SO_2 measurement is equivalent to the gas chromatograph-flame photometric or the flame photometric technique without prior gas chromatographic separation.

Concentration measurements of SO_2 by conductometric schemes exhibit the poorest correlation with respect to the West-Gaeke method of all the first-generation techniques. Although the conductometric instrumentation can be reliable in field service, the inaccuracy of the measurement of SO_2 concentrations makes this technique unsuitable.

Recommended Monitor for SO_2 and H_2S:

Gas chromatograph-flame photometric detection

Recommended Monitor for Total Sulfur Concentrations

Flame photometric detection without prior gas chromatographic separation.

Ozone

The specific measurement of ozone concentrations can be accomplished through a second-generation technique--measurement of the chemiluminescence resulting from the gas phase reaction of ozone and ethylene. This measurement can be made with the reaction chamber at atmospheric pressure and relatively simple instrumentation. In the presence of a known concentration of ethylene supplied by a compressed gas cylinder, the intensity of the chemiluminescence is a linear function of the ozone concentration in the sample gas. The instrumentation is reliable, accurate, and suitable for unattended operation in field installations. Chemiluminescent ozone measurement is recommended as equivalent to the reference method published in the Federal Register.

A third-generation scheme for the measurement of ozone concentrations in the atmosphere is based on ultraviolet absorption. Instruments based on ultraviolet absorption using a second-derivative detection technique and conventional Beer's Law absorption are available commercially. The ultraviolet absorption techniques give a specific measurement of ozone concentration and do not require a supplementary reagent, as does the chemiluminescent method. The ozone monitors based on ultraviolet absorption have not been on the market a sufficient length of time to evaluate their performance under field conditions. However, it is recommended that this technique be evaluated under field conditions within a research program of the RAPS.

The first-generation techniques for the measurement of total oxidant are based on colorimetric and coulometric measurements. Both the colorimetric and the coulometric measurements utilize the oxidation of buffered potassium iodide solution and a measurement of the free iodine released. These techniques do not give a specific measure of ozone but respond in a variable way to the concentration of NO_2 in the atmosphere. The presence of SO_2 also interferes with the colorimetric or coulometric total oxidant measurement and must be removed by a filter or scrubbers prior to analysis.

The direct measure of ozone concentration as with chemiluminescence or ultraviolet absorption is a significant improvement over the methods based on total oxidant using an applied correction factor for NO_2 concentrations.

Recommended Monitor for Ozone

Chemiluminescent ozone-ethylene reaction.

Suspended Particulate Material

The usual method of measuring the concentration of atmospheric particulate material is by high volume sample collection of aerosol on filters. The concentration of the aerosol is determined from the volume of air passed through the filter and the weight of collected particulate. This technique does not lend itself to unattended operation. Many manual steps are required--weigh filter before particulate collection at a known humidity, package filter for transport to collection site, place filter in high volume sampler, sample for known time interval at a known air flow rate, remove filter and package for transport to laboratory for weighing, weigh filter and collected particulate at a known humidity, calculate particulate concentration from sample flow rate and weight of collected particulate. The manpower requirements to obtain data on particulate concentrations with high volume samplers within a time frame similar to that of other pollutants is not feasible.

An alternative technique for particulate measurements is through the use of a particle mass monitor. Here an electrostatic precipitator deposits suspended particulate material on a quartz crystal oscillating at its resonant frequency. The resonant frequency decreases linearly with the total mass of the particulate deposition. The frequency of the circuit containing the sample crystal is compared to the frequency of a reference oscillator and the difference frequency is directly relatable to the mass of the particulate deposited on the sample quart crystal. If the sampler is cycled to sample for ten minutes every four hours, the sample crystal needs to be cleaned on a once-a-week basis. A respirable range attachment can be cycled such that the alternate readings will be total particulate and respirable particulate. However, though the principle of this automated technique makes particle mass monitors attractive for inclusion in the monitoring network, the commercially available mass monitors have proven to be unsatisfactory in service. The design and engineering of this type of instrumentation must be considerably improved before mass monitors can be recommended for inclusion in the instrument complement of the RAPS monitoring network. Specifically, fluorescent tracer studies indicate that particulate deposition other than on the sample crystal is experienced. Inefficient collection with respect to high volume samplers corroborates the findings of tracer studies. Measurements of negative masses or a weight loss of collected particulate during operation of the particle mass monitor not explainable by volatile aerosol or changes in humidity tends to indicate loss of particulate after deposition can occur. This technique should be reevaluated during the RAPS program to determine if adequate instrumentation can be or has been developed to fill the need of automated particulate measurements.

Another approach to particle mass measurement is through the attenuation of beta particles. A radioactive source emitting low-energy electrons in conjunction with a scintillator/phototube detector can determine masses of collected particulate as a function of the electron density of collected material. This technique, though not as sensitive as the oscillating crystal technique, does show promise for automation of particulate measurements. Commercially available instrumentation based on the beta-particle attenuation is or will be commercially available soon. The beta gage should be evaluated as to its potential application to the RAPS.

Since no automated procedure seems suitable for inclusion in the pollutant monitoring network, a compromise manual system of particulate collection and measurement is recommended for the RAPS. It is recommended that two conventional high volume samplers be employed at each station to collect aerosol on a sequential or concurrent basis. These samplers would be serviced by filter replacement during the normal twice-weekly station service call. Thus two high volume samples would be obtained per week per station. It is recommended that initially each sampler would operate for 24 hours to obtain an integrated sample on each of two selected days. Alternatively, the samplers might be run concurrently with one sampler operating during an interval of four hours during the day to characterize particulate concentrations as a function of time of day.

The second particulate measurement at each monitoring site will be that of atmospheric turbidity using an integrating nephelometer. This instrument will give a response related to the degradation of visibility. The integrating nephelometer through the use of a pulsed flash lamp detects the total scattered light from all scattering angles. The output of the nephelometer, the scattering coefficient, can be related to visibility in units of miles. The integrating nephelometer is a simple, reliable instrument, well suited to unattended operation in the monitoring station network.

Vertical profile particulate concentrations are not within the realm of practicality due to the losses of particulate while traversing long sample lines. Therefore, the particulate measurement with the particle mass monitor and the integrating nephelometer will be made at only one level--either ground or three meters above ground.

In addition, the results of the high volume sampler measurements taken by the Atmospheric Chemistry program would be integrated into the data collection system.

Recommended Monitors for Suspended Particulate Material

High volume sample collection on filters (2 required at each monitoring station)

Integrating nephelometer integrating-measurement of atmospheric turbidity

Summary of Pollutant Instruments

The following instruments are recommended for inclusion in the basic pollutant complement located in each of the network monitoring stations:

- Carbon Monoxide, Methane, and Total Hydrocarbons
  - Gas chromatograph, hydrogen flame detection
- Carbon Monoxide
  - Nondispersive infrared detection
- Nitric Oxide-Total Nitrogen Oxides
  - Chemiluminescent method, subject to evaluation at initiation of Regional Study
  - Coulometric, second choice if chemiluminescent evaluation negative
- Sulfur Dioxide-Hydrogen Sulfide
  - Gas chromatograph-flame photometric detection
- Total Sulfur Compounds
  - Flame photometric detection
- Ozone
  - Chemiluminescent method, ozone ethylene reaction
- Suspended Particulate Material
  - High volume sampler collection on filters
  - Integrating nephelometer, measure of atmospheric turbidity.

Instrument Calibration

Two separate systems of calibration are recommended for each network station to verify the accuracy of the pollutant monitors. The first consists of a local calibration capability permanently installed at each station. The second provides for mobile calibration vans to visit each station to more accurately calibrate the instruments and to maintain instrument standardization.

Local Calibration

The local capability consists of a two-point system for calibration of the pollutant monitors to be initiated upon an interrogation command or on a cyclical basis. This two-point calibration will establish the operating zero and the span of the pollutant monitor. A cylinder of high purity nitrogen simulating an air sample will serve as a zero gas to establish the true operating zero of the monitors. Compressed gas cylinders containing a known concentration of individual pollutants will be maintained at the station site to calibrate the span of the monitors. The concentration of the calibration gas must be chosen such that nearly full scale response can be obtained on one of the less sensitive ranges. The use of compressed gas cylinders containing very low concentrations of pollutants is to be avoided. The stability of ppm-pollutant concentrations during long-term cylinder storage is questionable with the uncertainty increasing at lower concentrations. The actual pollutant concentration appropriate for the calibration cylinders must be based on the stability of the pollutant. Compressed gas cylinders with known concentrations of the pollutant of interest will serve as span gas for CO, CH_4, NO, and H_2S. Of these pollutants, H_2S would be the least stable under long-term storage conditions.

The total HC monitor would be span calibrated based on its response to CH_4.

The SO_2 monitor would be calibrated using a permeation tube system. A permeation tube containing SO_2 and maintained at a known temperature would lose a known and predictable weight of SO_2 as a function of time through the walls of the permeation tube. A constant, low diluent flow over the permeation tube with subsequent dilution to an appropriate concentration will serve as a span gas for the SO_2 monitor. A commercially available automatic permeation tube calibration system would be used at each network station for SO_2 calibration. The same system could be used for NO_2 calibrations if required. The total sulfur monitor would be span calibrated based on its response to SO_2.

An ozone generator would also be used at each network station to span calibrate the ozone monitor. These generators are commercially available and are well suited to automatic calibrations.

The integrating nephelometer contains a built-in calibration system which would be used in this application.

It is recommended that all monitors be calibrated by a zero-span, two-point calibration at least once a week. It is also recommended that all instruments of the station complement be calibrated simultaneously.

The calibration manifolds and/or plumbing must be fabricated of material inert to the specific pollutant. The calibration schedule of of the network stations should be established such that only one network station will be in a calibration sequence while others are collecting data. The time required for calibration is estimated to be 1/2 to 1 hour. A digital flag will indicate on the data tape at the central facility when the calibration sequence is in progress at any network station.

Calibration Vans for Primary Calibration

It is recommended that three mobile vans be equipped with complete calibration facilities to perform four-point calibrations of all monitors located at network stations on a regular schedule. The calibration vans will intercalibrate monitors at all network stations. This procedure will ensure a continuity when standard calibration cylinders are replaced and will verify the accuracy of automatic calibration procedures.

The calibration equipment of the van will be similar to that of the integral station system, but will be operated manually by experienced technicians. This dual calibration procedure should permit recognition and correction of minor instrument malfunctions without significant data loss. With appropriate scheduling of the mobile vans, each network station would be calibrated once each month. It is estimated that one day or less would be required for a primary calibration of each station.

Role of Research Programs

Although specific research programs or areas of research interest are discussed elsewhere in this report, the relationship between research programs and the network air quality measurements should be clarified. Although the Class A stations will provide vertical concentration profiles of pollutants within the surface layer, measurements of both meteorological and air quality conditions above the surface layer will be needed by the on-going monitoring programs and a significant number of the research programs. These data needs can be provided by the use of balloon-borne instrumentation but more likely by special instrumented aircraft, especially helicopters.

It is unlikely that significant air quality measurements can be made by balloon-borne sampling techniques although equipment is available for ozone and total particulate measurements from balloons. In a congested urban area such as St. Louis, it will be necessary to rely upon high performance helicopter operations to provide the detailed vertical sampling for air quality data that will be necessary in the research program.

The helicopter to be used in this program will have to be of at least medium size so that the carrying capacity can include both a technical observer and several hundred pounds of instrumentation. With such a load, the performance of the helicopter should be sufficient to permit it to climb to an altitude of 4000 or 5000 ft in a time period of 15 or 20 minutes. There is no standard instrument package available for airborne sampling and thus an initial research project associated with the RAPS should be the design and development of a research instrumentation package to be used aboard an available helicopter. This research project would obviously require specification of the type of helicopter to be made available to the program.

Another research area of interest to the monitoring network is the establishment of measurement correlations between the first-generation pollutant monitors with the specific detection of the second-generation monitors used in the network stations. A wealth of data has been accumulated from a variety of aerometric studies by pollutant monitors employing first-generation measurement techniques. The RAPS provides a unique opportunity to correlate and intercompare measurements obtained by the older equipment with modern monitors under real conditions. Precise establishment of correlations could give new meaning to old data and provide updated information about pollutant concentrations without the expense of new aerometric surveys. These correlations could be of direct help to control districts using first-generation monitors and could identify monitors and equipment that need to be upgraded.

A similar need exists for evaluation of new instruments and techniques. The measurement correlation program established for new instruments would be primarily a field evaluation and not a feasibility study for new concepts. Establishing the feasibility of instrument concepts in the development of new concepts is an ongoing program in the EPA.

A case in point is the Fourier Transform Infrared Spectroscopic system. This measurement system uses a Block interferometer in conjunction with a dedicated computer to analyze trace gases in the atmosphere. This measurement technique, a development of EPA, has undergone limited field testing to assess its potential as an air quality monitoring instrument.. The Fourier Transform Spectrometer appears to be a very promising measurement technique. The sites and back-up support provided by RAPS could provide the vehicle in terms of field experience to complete this and other new concepts in instrumentation.

Chapter XIII

DATA ACQUISITION AND HANDLING

Introduction

The Regional Study will require data from an extensive network of air measurement stations distributed over a large urban and rural area. Extensive measurements of meteorological parameters and of a number of specific and general air contaminants will be made at these stations at intervals of less than 1 minute to several hours. A rough estimate of the total number of measurements per day is about 1-1/2 million.

The Regional Study is intended to provide a continuous, organized data base for a wide variety of research programs. The data collected must therefore meet the usual standards and criteria for a good set of experimental data. They must be reliably recorded with sufficient resolution; every item of data must be unambiguously identified, and all measuring devices must be periodically calibrated at intervals based on operating experience. Because of the large number of instruments and the geographical spread of the stations, all of these activities should be performed automatically.

The goal will be to provide sufficient data identification and documentation on the primary data recording tapes so that they can be deciphered and used without any supplementary documentation.

Policies and Principles

The design of the recording system and the data formats will be guided by these principles:

- All data must be individually and automatically identified. Each instrument should have a unique identifier code which will be recorded together with the value of the measurement.

- Information should be recorded in "free field"* formats. This will permit unrestricted extensibility of all available levels of information on the tapes without obsoleting the formats of any previously recorded data.

- Tape is cheap; it should be used freely for descriptive comments about any special conditions. In particular, there should be a fully descriptive header on each tape, in English, describing any nonroutine research instrumentation that may be recorded on that tape.

- All codes should be translated into understandable quantities as early as possible. The data transmitted from the stations will be binary-coded representations of output voltages and instrument identifier codes. These should all be immediately recorded on a primary archival tape. The central computer should prepare secondary archival tapes in which all the measurements are in engineering units, corrected for the instrument calibrations, and the instrument identifiers are translated into readable descriptors.

- All manually collected data should be recorded on tape in the same formats as the automated data. The standby computer and a teletype can be used to transcribe such data via a computer program that will write it on the tape in the proper formats for future analysis.

System Overview

The system will comprise a large number of discrete stations distributed over the instrumented area. It is presently estimated that there will be at least 49 stations (see Figure XIII-1) linked to a central data acquisition system, of which 17 or more will be provided with 30-meter tall towers for vertical profile sampling, and the others will be semimobile or transportable units that may be relocated occasionally as the program develops. There will also be a group of self-contained instrument stations, recording data locally on tape, and not connected to the central computer.

The stations will contain varying complements of meteorological and air sampling instruments. The tower stations will especially concentrate

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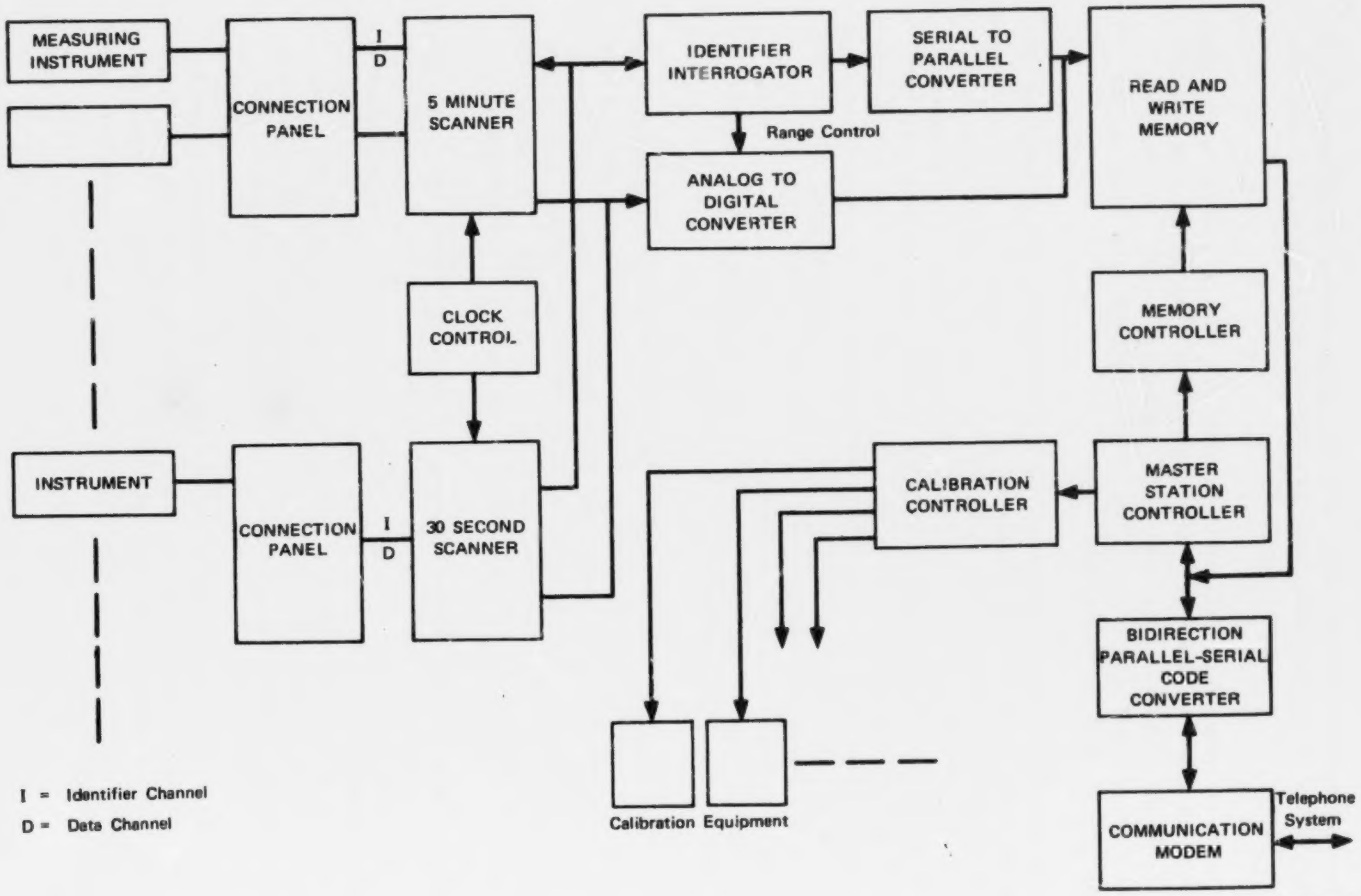
* See data formats.



SA-1366-2

FIGURE XIII-1 INSTRUMENT STATION DATA AND CONTROL SYSTEM

on gathering meteorological data, and the semipermanent stations will be focused on air pollution measurements, but all stations will record at least a basic set of both kinds of data.

The wind components, air temperature, and humidity will be recorded at 30-second intervals and at 3 different elevations at each of the 20 tower stations. Most of the pollution measurements will be taken at 5-minute (or longer) intervals. The meteorological data will be the largest set of data to be transmitted.

The stations will be connected to the regional central computer by telephone. The lines may be leased or dial-up, depending on cost factors not yet known. The computer will query all the stations at 15-minute intervals to gather the data. Because the instruments will be sampled locally at more frequent intervals, each station must have a temporary data storage device to accumulate data for 15 minutes. This arrangement will simplify and speed up the data transmission to the central computer, because it will not have to stay connected to a station long enough for an electromechanical scanner to scan all the instrument channels, but only long enough to read out the memory device at the station. This can be read at data rates limited only by the telephone line capacity, which should be at least 2400 bits per second.

The tower stations are estimated to make about 500 measurements in 15 minutes. Each value will require an 8-bit transmission code. Identification of the type of instrument, the instrument number, and the position, should require 2 or 3 more 8-bit codes per value. The entire 15-minute data block can be transmitted in 5-10 seconds. The data from the smaller stations will require about 2 seconds for transmission.

The computer at the central facility (shown in Figure XIII-2) will convert the raw primary data to secondary data in engineering units. It can do this during the slack time in each query cycle. The data from each station will be written as it is received on a primary archival magnetic tape and also temporarily on a fast access disk memory. The disk memory will be large enough to hold in a more permanent file area all the current calibration data for all instruments, and also a thesaurus table of readable identifiers corresponding to the transmitted instrument identification codes. At the end of each station transmission, the computer will access the data block on the disk for that station, compute the calibration corrections, convert values to engineering units and identifier codes to descriptors, and write the secondary record tape while doing this.

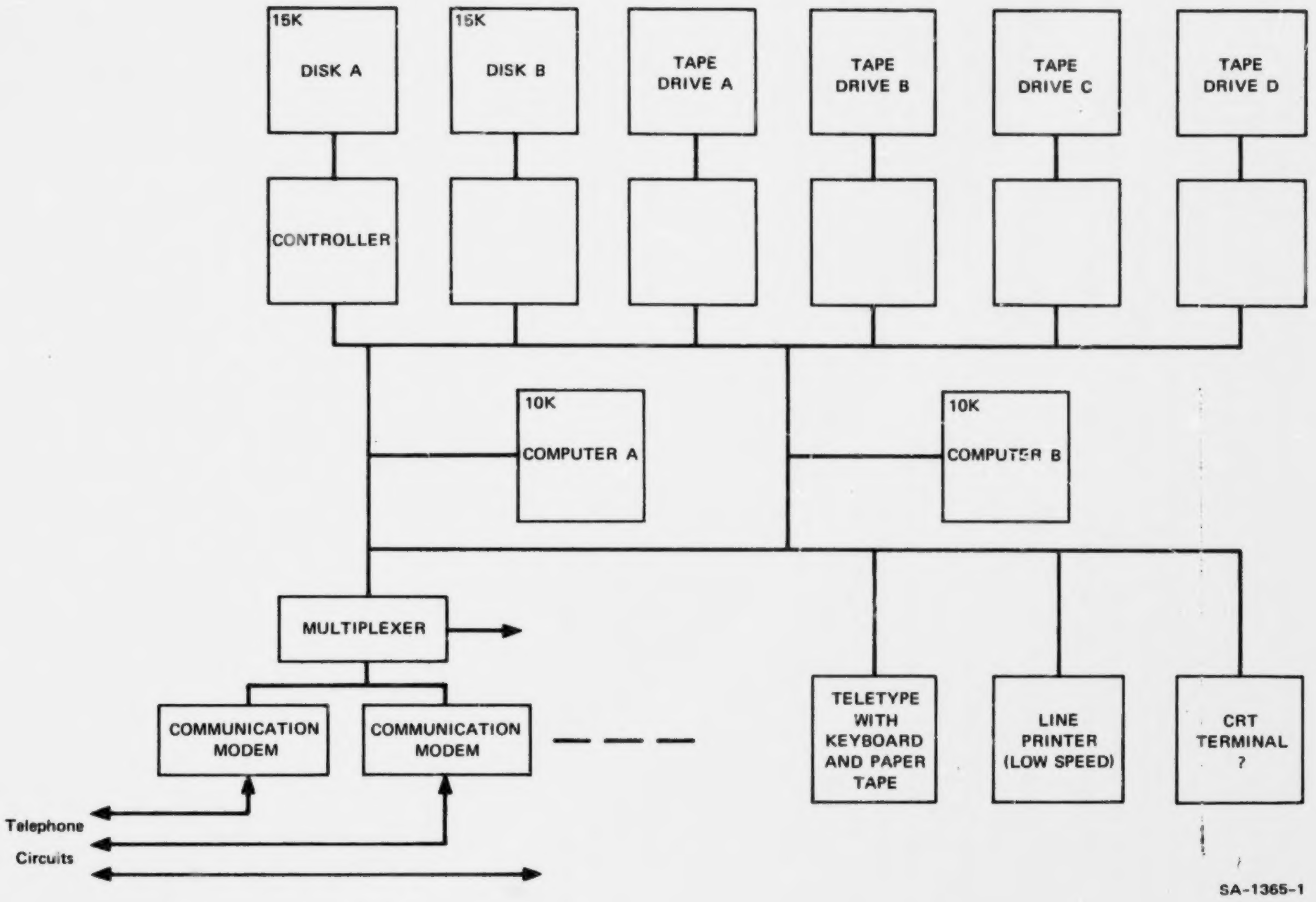


FIGURE XIII-2 CENTRAL FACILITY DATA PROCESSING SYSTEM

The most recent portion of the secondary record will also be recorded on another portion of the disk for system monitoring purposes. This will be accessible by the stand-by computer as requested by staff personnel and can be printed or displayed on a CRT output terminal. The main reason for having a stand-by computer is to take over the data acquisition task whenever the first computer needs maintenance. It can be used for data monitoring, entry of manual data to tape, and other computational tasks when both computers are operational.

The disk memory at the central site will require sufficient capacity for at least two full sets of calibration data, at 2 values per installed instrument, so that each new calibration, as it is received, can be compared with the previous one to detect any anomalous behavior of either the instrument or the calibration system. It must also contain a table of conversion factors to engineering units, the library of the identifier codes, and the English language descriptors for about 2000 separate active instruments, plus room for about one hour's worth of monitoring data, and a "scratch" area for writing the input data for each station.

Instruments

Most of the meteorological and air sampling instruments will be devices that measure continuously and generate a DC output voltage proportional to the quantity measured. Instruments of this kind are easily recorded by connecting their outputs to a multiinput scanner device which periodically connects an analog-to-digital converter to each input terminal.

A few instruments, such as automatic gas chromatographic analyzers, operate intermittently. They may require a fixed quantity of air to be processed through an analytical cycle, or may have some other internal cycling operation, so that the measurement appears at the output terminals at periodic intervals. Data recording from instruments of this kind can be done with either a synchronous control system, in which the instrument is initiated by an external timer, or by an asynchronous polling system which either keeps polling the instrument to find out whether it has a new datum, or is signaled by a code initiated at the instrument to record the data. It appears that the best choice for data acquisition control in these stations will be the use of a single-cycle controller for the entire station. This method will not require any modification of most of the instruments, but will require a capability in the intermittent instruments of being reset and started on a new cycle by an external signal.

A few instruments can measure more than one quantity during a single instrument cycle. One gas chromatographic analyzer will measure CH_4, CO, and total hydrocarbons as it goes through its analysis of an air sample. The most straightforward way to fit such an instrument into the scanning pattern is to require that the instrument be equipped with separate output circuits for each component that it measures. Since the timing or recognition of the separate peaks will be a function of internal instrument parameters, such as flow rates, it would be very difficult to synchronize an external scanner to the characteristics of each instrument. A better procedure is to connect an instrument that measures three different components to three different scanner input terminals, with three different identifiers. This application may require that the instrument be extensively modified. It will require internal capability for identifying each component peak, and converting the peak height (or the integral of the peak, depending on the nature of the device) to a voltage that can be routed to the appropriate output terminal and held constant there until the reset signal starts the instrument on the next measurement cycle.

Some instruments provide output voltages in the 0-100 millivolt range, and others produce 0-5 or 0-10 volts. An analog-to-digital converter with automatic range switching can be used in the system. This will be much less expensive than equipping each of the low output instruments with a stable DC amplifier. The range setting of the converter can be provided as part of its digital output code. It may increase the number of bits associated with the measurement by 2 or 3, depending on the number of range settings needed. Alternatively, the instrument identification code can also specify the converter range setting, and avoid the necessity of providing it as data.

One of the most serious problems that must be faced in any system for handling very large amounts of data, whether automated or not, is the identification of each datum. For this reason, every instrument should be self-identifying to the system, so that the researcher who is using the data much later does not have to find log books and laboriously correlate the notes made by instrument installers with the recorded data sets. In addition, human errors in recording channel numbers, or accidentally interchanging a pair of signal leads in a large bundle out of sight of the actual instruments can ruin a large amount of data. The problem essentially is that there are many information transfers in the identification process, and every one must be correct.

We are proposing a method for instrument identification that will be automated in complete parallelism to the data itself. The data from a given instrument come out of a cable into a particular input channel connector on a data scanner. The instrument identifier device should be physically mounted on the instrument and connected by the same cable carrying the measurement signals to a multicontact scanner connector. The identifier unit might consist of a 16-bit shift register and a 16-bit read-only memory. These are inexpensive solid state devices. The read-only memory should contain the instrument type code and instrument number, which would be written into it when it is installed in the instrument, and also painted or stamped on the instrument panel where it can be easily seen.

Information, such as sampling height or other static data, may be implied by or included in the instrument identifier code. If a more dynamic indication is needed, as, for example, a flow rate indication for a specific instrument, that can be regarded as a separate measurement and assigned to a "pseudoinstrument channel."

The master controller is a device that interacts directly with the central computer via the telephone system. It has the following functions:

- Establish communication with the central computer by responding to a signal from the telephone data set with the station identification code.
- Recognize the control commands sent by the central computer after the computer recognizes the station.
- Send control signals to the local necessary unit, the scanners, the calibration controller, and any other station systems or instruments specified by the computer.

Data Acquisition Equipment at Stations

The measurement and identification data from every instrument must be periodically collected, digitized, and forwarded to the central computer or stored locally. This equipment is described below primarily in terms of the various functional units that are required. Most of these units are available as commercial items, with the exception of the instrument-mounted identifier and the interrogator, for which a specific detailed design is described. However, it may be advantageous to have the data acquisition systems custom-manufactured, because of the number of them that will be required to equip all the stations.

It is assumed that all instruments will fall into one of two classes. In one class, the output of each instrument will be sampled once each 30 seconds. These instruments will be sampled in sequence and one complete cycle will take 30 seconds. Instruments in the second class will be interrogated once each 5 minutes and, consequently, a complete sampling cycle will take 5 minutes. The fast and slow instruments would be connected to separate scanners that provide paths from each instrument to the common equipment that generates interrogation commands and stores the resulting measurement and identification code data in a memory unit. It is assumed that the scanner provides three paths between each instrument and the common control circuits. One path is provided for the analog voltage output of the instrument, one for command information from the interrogator to the identifier, and the third for output of the identifier that is sent back to the common control.

The identifier unit would generate a 16-bit serial identification code. In one simple implementation of the identifier circuit, an integrated circuit shift register and a few gating circuits would be required. The read-only memory that contains the instrument identification could be realized in a set of metallic conductors on the printed circuit board that mounts the shift register and logic ICs. The conducting paths would be broken (by physical removal of the metal) according to the desired identification code. DC power for the identifiers would be provided from the centralized control circuits on a continuous basis (there is no need to go through the scanner paths). An initial pulse to load the shift register with the ID code and subsequent clock pulses to shift the code out of the register would be provided from the centralized control circuits through the scanner paths. It is reasonable to expect that an identifier unit might occupy a volume of 4 or 5 cubic inches and be made for less than $50 in quantities of several thousand units.

The identifier function could be realized by a simple circuit like that shown in Figure XIII-3. Its input is a series of 17 pulses, the first being an initiate pulse and the next 16 being clock pulses for the shift register. A control flip-flop, whose function is to direct the incoming pulses either to the set parallel input or to the shift terminal of the shift register, is normally held at the output of a one-shot circuit in the condition for sending the incoming pulse to the set input. Consequently, the first of a series of pulses sets the identification code into the shift register. The trailing edge of the first pulse triggers the one-shot circuit and removes the holding signal on the flip-flop. The trailing edge of this pulse, stretched out by a series capacitor, also causes the flip-flop to change state so that the following input pulses are sent to the shift terminal of the shift register. The serial input of the shift register (connected at the most significant

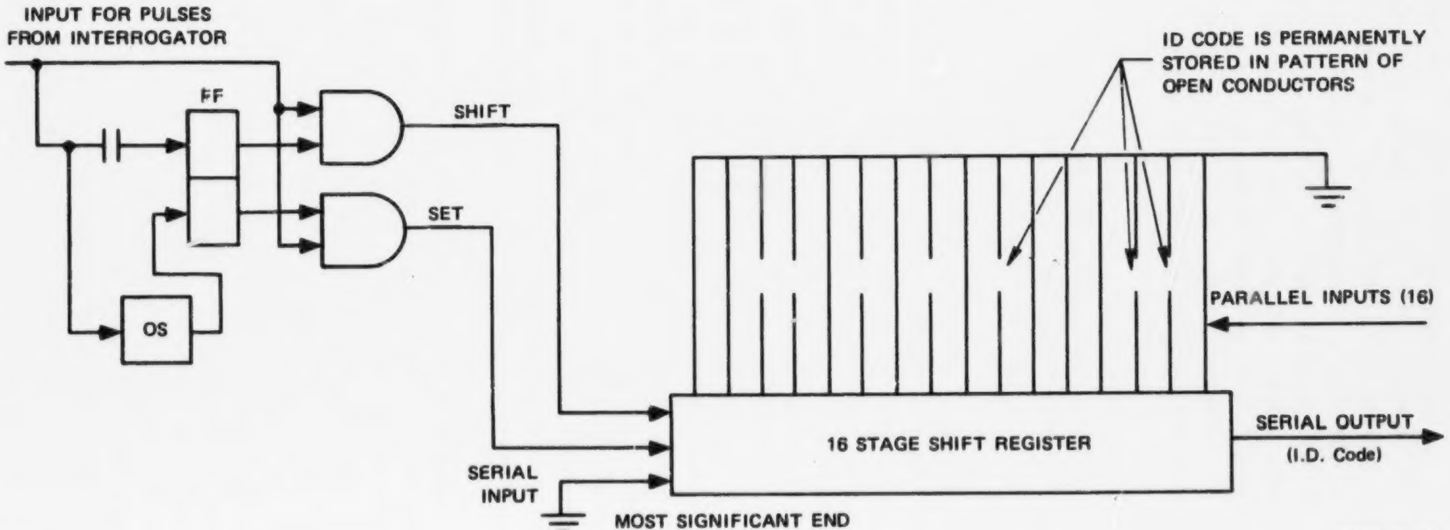


FIGURE XIII-3 LOGIC DIAGRAM OF INSTRUMENT IDENTIFIER

end) is grounded and, as the ID code is shifted out, zeros are shifted in. At the end of 16 cycles, the register has been cleared and is ready for the next interrogation. The one-shot circuit returns to its normal state shortly after the end of the 16th pulse and the control flip-flop is again held in its quiescent state. Off-the-shelf ICs needed to build the circuit cost about $20 in quantities of 100, at the present time.

One set of centralized control and storage circuits could be used to service all instruments. It appears that solid-state random access memories are becoming cheap enough to provide an attractive method of storing measurement and identification data during the 15-minute interval in which data are accumulated (at present prices, storage for 4,000 8-bit words would cost about $1500). Since the input to such a memory is in parallel form, the serial identification code that comes from the identifier would have to be converted to parallel form. This could easily be done in an 8-bit shift register. After the first eight bits of the ID code have been shifted from the identifier to the register in the centralized circuit, the parallel output of this register could be gated to the memory. When the next eight bits have arrived in the shift register, they can be gated to the memory. Then the output of the A/D converter, which is normally in parallel form, could be gated to the memory. Thus, for each instrument interrogation, three 8-bit words would be put into the solid-state memory.

In addition to generating control pulses for the instrument identifiers and transferring data to memory, the central control circuits could control the connection of the high and low speed scanners to the common equipment and provide stepping pulses for the scanners. It appears that the required complexity of control may be substantially less than the capability provided by commercially available scanners. There appears to be a high probability that a system including scanners, A/D converters, control circuits, and memory that is specifically designed to meet the requirements of the EPA regional operation might be substantially less expensive than a system designed around commercially available equipment, in particular commercially available scanners. This approach would appear especially attractive if no exotic requirements were added to the basic requirements of sequentially interrogating all instruments in the station. It would not be difficult, for example, to provide the capability of stopping the interrogation sequence on any selected instrument and displaying the measured output visually. Further, a relatively simple A/D converter could be used with instruments having a wide range of output voltages (100 mV to 10 V, for example) by using a small part of the ID code to set automatically the input range of the A/D converter. Compatibility with a serial communication modem could easily be achieved by transferring the contents of the memory in parallel form to an 11-stage shift register in which the conventional start and stop bits of the 11-bit ASCII code are automatically attached to the eight bits of data. Shifting out of this register would give the ASCII characters in the serial form that is required by communication modems.

The central control circuits mentioned above may be considered to be a part of the station master controller which provides for control of all the operations at each station.

The master controller will contain the read-only memory device that holds the station identification code, so that it can verify to the computer that it has called an instrument station and can proceed to collect data. About 4-6 different commands may be used to control the station, so the controller can be a hard-wired logic device, with fixed output signal wiring.

The time at which measurements are taken need not be transmitted in the data stream, because the scanners can be reset to the beginning of a cycle when the computer calls for data, or by computer command even if the data transmission interval is chosen to be different from the data recording interval. The accuracy of the clock controlling the scanners will be adequate for determining time relative to the time value recorded on the tape by the computer each time it resets a station scanning system.

Each station must also have a calibration controller. This equipment will operate all the relays and valves required to perform the physical calibrations of the instruments. Each instrument that can be calibrated should be read for zero and full scale. The logical procedure is to calibrate all the instruments in the station at the same time, because only one command is needed, and because data analysis that uses several items of data from a station will be least interfered with if all measurements are available or all missing. The calibration procedure for a typical station may take two 15-minute measurement cycles, because many of the chemical analysis instruments require several minutes to equilibrate after a large change in the sample gas.

The on-line stations also require a modem and a data set to couple into the telephone network. These are standard data communication devices and are readily available.

The self-contained stations will require similar data acquisition equipment, except that the station controller will have its own clock, rather than be controlled by signals from a computer. The controller will otherwise perform the same functions as it does in the on-line stations. The local recorder will also be different. It must have tape capacity to accumulate several days' data, if necessary, before the tape is manually replaced. It will not require any read-out capability.

Data Formats

The standardization of data formats is always a troublesome problem. For efficient computer operation, the data formats should be rigorously defined, including the exact number of bits in every value, and the number of values in every record. Identifier codes and labels are often packed into the smallest possible number of bits, and the sequence of numbers is standardized so that identification is implied by the position of a value in a record. In spite of the advantages of minimizing storage space and computer running time, there are very serious drawbacks to this approach. Once the format is established, there is no room for expansion without making a new format. All measurements are limited to the predetermined resolution, and there is usually no way to deal with special research requirements that were not initially planned for.

A much better approach for handling data in a research environment is the concept of "free-field" recording. Free-field information recording is usually character-oriented, rather than bit- or word-oriented. A few special characters are chosen to have special meanings. These are not part of the data, but serve as identifiers to the computer to recognize elements in the data stream, or changes in the data type. Generally, a computer does not read free-field data as quickly as it reads formatted data, because it must examine every character to test whether it is one of the special characters. The process can be made somewhat more efficient at little added cost in storage space by choosing only one such "escape" or signal character. Its significance to the computer is that the next following single character is a data code descriptor. This speeds up reading because the computer makes only one test on each character to determine whether or not it is the escape character. It makes more detailed tests only on the character following the escape character, and otherwise reads the stream of characters into appropriate formats determined by the current data group that it is set for. The escape character also is automatically the terminator of any data group.

This free-field coding will, for example, accept a sequence of 8-bit identifiers and values, then perhaps a 16-bit value, then maybe a comment in English describing some special experiment recorded in that portion of the tape, back to some more data, and so on.

The standard ASCII (American Standard Code for Information Interchange) code is a defined set of 128 characters, each using a different 7-bit code. The character set includes all the upper and lower-case letters, the 10 digits, many punctuation, arithmetic, and logical characters (such as !, ", $, @, +, and #), and a group of 32 special communications control characters. An eighth bit is normally transmitted as part of each character code block for use in parity testing for transmission errors.

An 8-bit character can be used to represent integer values from -127 to +128, thus providing at least 1% resolution of either positive or negative values, depending on where the effective value of zero is defined to be. One of these characters will be taken as the escape character and another as null (not zero), reducing the number set to 254 characters. There are then also 254 possible different data code identifiers, even if this function is restricted to only one character. This is probably many more than will be needed, but the reserve will be helpful whenever new code categories need to be introduced. The most important code categories are:

- 16-Bit identifier (two 8-bit characters)
- 8-Bit numeric data
- 16-Bit identifier + 8-bit numeric (three 8-bit characters)
- 16-Bit identifier + 16-bit numeric (four 8-bit characters)
- 16-Bit identifier + "no-of-characters in following numeric" + numeric
- Zero-point calibration state
- Full-scale calibration state
- Measurement state
- Comment
- 16-Bit unsigned integer
- 32-Bit signed floating point number.

These category codes are essentially announcements to the computer that is reading the tape to tell it how to interpret the following record up to the next occurrence of the escape character. For practical reasons, there needs to also be a null character, corresponding to no information or blank space. A convenient representation of null is 00000000, and an obvious representation for an escape character then is 11111111.

With this free-field system, an unbounded number of instruments, resolution levels, types of data, and lengths of data records can be managed. We strongly recommend that any standardization of data formats be established at this information processing level.

The Central Data Collection Facility

Overview

It is envisioned that there will exist a single data collection computer facility to serve the entire data collection network. Data from all the measuring sites would be transmitted via telephone communication links to the facility. The computers would be in continuous operation on a 24-hour basis, every day of the year. During normal working hours, it is expected that the facility would be attended, and also routinely used by some research personnel. Outside of these hours, the facility might be unattended or supported by a single person; this should not preclude the use of the facility by research personnel during the out-of-normal hours.

Two major outputs from the facility would be (1) "clean" data tapes for use by research personnel, and (2) "raw" and clean data tapes for archival purposes.

Reliability of the data collection process would be promoted by proper configuration of the equipment and the limited use of redundant equipment. The unavailability of any critical element (including the source of electrical power) whether due to a failure or routine maintenance, should not interrupt the data collection process. For example, it is likely that a single minicomputer will be able to perform all critical data collection tasks, but will lack the capacity to process the data to produce clean tapes. This latter activity, plus others, might be handled by another such computer. If these two computers are chosen to be identical, that computer engaged in the nonessential activities can be switched to the data collection task, if the other computer fails while collecting data.

Functional Tasks

Thus far, five major functional tasks have been identified for the data collection facility, (1) control of data collection, (2) maintenance of data quality, (3) production of clean output, (4) archiving of data, and (5) real-time observation of data. These tasks are grossly described below. At this time, it is premature to discuss either the detailed data processing activities, or the details of the facilities hardware.

Control of Data Collection

It is necessary that the data collected at each site be collected periodically, in an orderly and timely manner. Present thinking about the computer facility provides for a high degree of sharing of the computer's time, storage, and programs in the data collection activity. This form of sharing is common practice in large, medium, and small systems as a means of achieving substantial economies with little or no sacrifice in performance.

To effect this sharing, the computer must control the order in which the instrumentation sites are allowed to talk to the computer. When the computer determines it is prepared to accept more data, it selects the site to be so permitted and then sends a message to that site informing it to proceed. After the site has completed transmission, the computer can repeat the cycle with another site. If transmission difficulties are encountered, the computer may request retransmission of the data; in the case of a bad dial-up circuit it may redial the site or, if a persistent problem is encountered, the computer can immediately produce a trouble report.

Maintenance of Data Quality

The computer can check the values of each received datum for reasonableness. Such a check could compare the datum or its rate of change with an upper or lower bound that is associated with that measurement. A datum can be compared with other data values, for instance, the difference between two independently measured temperatures can be compared with the directly measured difference.

Where a check yields an out-of-bound result, the computer can immediately produce a trouble report so that an investigation, and possibly corrective action, can be undertaken by the proper persons.

Production of "Clean" Output

It is anticipated that the data desired by the research personnel should be easy to work with. The data as received from the site are expected to be "raw" in that they will be (1) in unusual units of measure, (2) without calibration correction, (3) confusingly related through codes to the specific instrument and quantity measured, and (4) interspersed with items of "control" information. The computer facility should remove these undesirable features and produce clean data: actually the researcher could and, in some instances, might undertake this task himself. It is expected, though, that the complexity and burden of the effort will make this an undesirable task for him.

The clean output will have the data in such a form that (1) each datum is in the units commonly used for the specific application, (2) each datum will have been corrected on the basis of the latest calibration data, (3) each datum will be clearly identified as to the nature of the quantity measured and the source instrument, and (4) no extraneous information will be present.

Archiving of Data

A data-archiving process will be used. As a minimum, the raw data obtained from the sites, including calibration information, will be archived. These data will likely not have been processed significantly by the computer as it records them on magnetic tape after receipt from the sites. The clean data can also be placed in the archive, although it will be possible to derive the clean data from the raw data in the archive.

Real-Time Observation of Data

As an aid to the conduct and design of experiments and the maintenance of the instrumentation network, it should be possible for research and operational personnel to monitor the data being collected by the central facility. The monitoring should be under the control of the observer(s). Thus, the observer should be able to specify which specific measurements and specific sites he desires to observe. He should be able to examine the data just gathered at the facility, or the last value received, or the values over a short previous period (e.g., during the preceding hour). Some simple cathode ray tube displays may greatly aid in the presentation of data plots of data simultaneously gathered from several sources.

Equipment Complement

We can identify the major components of the computer facility.

Communication I/O Multiplexors

These items serve to couple the many communication lines from the instrument sites to the computer system. Under computer control, the device can effect the simultaneous exchange of information with one or more lines.

CPUs and Main Memories

The CPUs (central processing units) and their memories do all the information processing tasks, including the control of information flow to display terminals and disk storage units. Two CPUs are envisioned, one concerned with data collection activities, and the other with the production of clean data tapes and the displays. Different programs serve to differentiate these two identical CPUs.

Disk Storage Units and Tape Units

The disk storage units provide storage of the most recently collected measurement information, instrument calibration data, and data validation limits. The tape units provide the long-term storage of all the collected data. When one reel of tape is filled, it is placed in the archive or delivered to a researcher and a new reel is mounted on the tape unit.

Displays and Other Output Units

Cathode-ray tube display units are for use by researchers and the operational staff, to observe the current and recently captured data. These data are kept on the disk units. Via the keyboard of the display unit, a person can send messages to the CPU, directing the CPU with respect to the particular data items to be shown, the formats, and so on.

Disk File Organization

A large amount of data must be kept on the disk, at several different levels of permanence, and for different functions, as described previously. Although the exact details of the data organization will depend on specific implementation factors, such as the hardware and operating system and programming language capabilities of the computer that will be chosen, a few general statements and suggestions about data organization can be made.

The reason for using a disk memory is to provide random access to data. However, that capability must be used with the total system operation in mind, because it requires about 16 milliseconds per access on a typical head-per-track disk memory, and a longer time with a moving head disk system. A very large number of disk access requests for processing one item of data can use more time than is allowable for this system. Therefore, it is necessary to organize the data on the disk so that the number of accesses used per operation is not excessive.

The data stream, as it is received from each station, can be written sequentially in a reserved "scratch" area of the disk, on top of the data from the previous station transmission. This requires only one positioning operation for writing the data and also for reading it, because it can be processed in the same order it was received.

The processing of the data will require access to the calibration and the descriptor for each instrument. These can be located together in a single contiguous table entry whose "disk address" is computable from the instrument identifier code. Thus, as the received record for each instrument is read by the computer, it can compute the location of all the information needed to calculate the corrected reading in suitable units, and also the readable description of the instrument, for recording on the secondary archival tape and on the monitor portion of the disk.

To facilitate the use of free formatting of measurements and descriptors, and also to conserve disk space, it is probably better not to preassign file space to specific instruments, or to predetermine the length of field needed for each instrument, but rather to write compactly on the disk, and maintain an integer-coded "disk address directory" to the locations of all information relating to specific instruments, both in the reference files and in the monitoring data. This indirect addressing can be organized hierarchically by stations and by instrument types, and can be utilized by the monitoring display program, as well as by the on-line data processing.

Manual Data Entry

Because the Regional Facility will be used to support a wide variety of short-term research programs in addition to its routine data collection operation, there will be many occasions on which experimenters will make measurements without using the automatic data collection system. In order for such data to be available for later computer analysis in combination with the basic meteorological and air quality data, they must be entered on data tapes in appropriate form. This data entry operation can be done by using the standby computer, the terminal, and the tape equipment. There are several approaches that can be followed to assure that all data are entered in a readable form.

One way is to depend on a trained data clerk, who would know all the details of the various data formats, and be skilled at copying data. This procedure probably would require, however, that each experimenter first transcribe all his data from the laboratory notebook form to some standardized tabular form. This may be necessary if there is a large amount of such manual data entry, but if there is only sporadic activity of this type, it may be more practical for the experimenters to learn to enter the data themselves.

Two kinds of support will be needed to assist visiting experimenters to correctly record their data. First, a well-written manual, containing a variety of examples of data sets from various kinds of experiments, should be provided for study and reference. Second, the data should be entered through a computer program that is designed to assist the user by requesting data in the correct sequence, doing whatever verification can be done easily, and generating the correct formats and format codes for writing on the tape. This program should be written in a high-level language so that it can quickly be modified as needed for special cases.

The staff programmer should be available to advise or instruct those who need to use the manual data entry procedure, and to progressively improve the data entry program to provide most of the assistance.

Other output units include line printers and console typewriters. Via these devices, data and messages can be printed.

Reliability Considerations and Maintenance

We assume that it is intended for the data collection to proceed on a continuous basis. This being the case, provisions must be made to accommodate the incidence of the more frequent types of malfunctions and the needs for routine maintenance. Only two of the five functional tasks are critical--control of data collection, and maintenance of data quality. When the other functions are sacrificed, then the CPU, storage, and other system resources thus freed are available for use by the critical tasks. Consider the simple case where it is necessary to remove from service the CPU controlling the communication lines. By loading a new program into the other CPU (which had been producing the clean data tapes and running the CRTs) the CPU can assume the communication control task.

With these constraints, we see the need for dual communication I/O multiplexors, dual CPUs and memories, and backup disk units and tape units.

Two independent sources of commercial a.c. power should be provided. A separate, independent standby power source seems unwarranted for, if a serious power failure does occur, it is likely that many instrument sites could be affected too.

If air conditioning is needed, consideration should be given to the use of a backup unit.

Communications for the Data Collection Network

The Telephone Companies

A set of about 12 telephone companies have been identified as serving the area around St. Louis that is encompassed by the data collection network. Some are very small, such as the Orchard Farm Telephone Co. of Orchard Farm, Mo., which serves a population of 706. The Staunton Telephone Company of Staunton, Illinois does not even have a listed telephone number. Actually, we need only be concerned with the three major companies--Illinois Bell Telephone Co., Southwestern Bell Telephone Co., and Continental Telephone Corporation.

In practice, it is likely that those responsible for the operation of the network will need to deal with only Southwestern Bell, especially if all the communication lines terminate in St. Louis. Where the facilities do not reach to St. Louis--consider an instrumentation hut in Orchard Farm, connected only to a local dial-up line--then these many companies may need to be individually dealt with.

Facilities

Only a limited number of communication facilities have been considered at this time. These are: (1) full duplex leased circuits, (2) circuit treatment, (3) modems, and (4) data couplers. Not considered were (1) dial-up service, (2) automatic dialing units, and (3) automatic answering units. A very brief functional description of each of these items is listed below.

Full Duplex Leased Circuit--This is a voice-bandwidth transmission facility that interconnects two specific points; this circuit is available 24 hours per day every day of the month for the sole use of the customer. Being full duplex, it is possible to transmit simultaneously a different signal in each direction. Depending upon the terminal equipment, either voice or data signals can be sent.

Circuit Treatment--This is a special adjustment made to the circuit to improve its frequency response. This type of adjustment permits data to be transmitted at rates in excess of 2000 bits per second, though less than about 10,000. Special telephone company equipment is attached to each end of the circuit to provide the treatment.

Modems--These are items of equipment that couple data equipment to the communication circuit. They transform the digital signals received from the data equipment into a signal of a form compatible with the communication circuit; and vice versa. Typically, a single modem will provide both functions simultaneously. One modem is required at each end of a circuit. The rate at which data are transmitted is controlled by the modem: our interest is in data transmission rates in the range of 1200 to 2400 bits per second, though rates very much slower and very much faster are also in common use.

Data Couplers--If the equipment connected to the circuit (the modems) is not telephone company property, then this device, supplied by that company, is required by law. Such a condition arises when nontelephone company modems are used.

Dial-Up Service--This is the type of service provided users of regular telephone service. With this service, the originator of the call must "dial" the number of the desired party. A circuit between them is set up, if possible, and maintained for the duration of the call. If the called party is busy or does not answer, the circuit cannot be completed. There is also a finite probability, the order of 0.05, sometimes greater, that a shortage of circuits will also prevent the call's completion. The dialing time, and the switching time at the central office, can delay the set-up of the circuit by as much as 15 seconds. The quality of the dialed circuit may be poor--typically only data rates of less than 2000 bits per second can be used.

Automatic Dialing Units--This is a device that is required to enable an item of automatic equipment, such as a computer, to "dial" the call. With such a unit, automatic placement and termination of calls is possible.

Automatic Answering Units--This is a device that is required to enable an item of automatic equipment, such as an unattended data collection system, to answer a call.

Costs

Detailed cost analyses are not possible at this moment, primarily due to the complexity of the rate structures. Factors in this complexity are (1) whether or not the service crosses a state line; (2) if entirely within a state,the particular state of concern, i.e., Missouri or Illinois; (3) for a given state, whether the service crosses telephone company boundaries; and (4) for a metropolitan area, whether the service is entirely within that area or not.

For the moment, we can ignore these many factors and use the following costs. These are conservative because the actual costs will probably be lower.

Full Duplex Leased Circuits--$4 per mile per month for circuits wholly within the St. Louis metropolitan area, $3 per mile per month for all other circuits, and $30 one-time installation charge per circuit.

Circuit Treatment--$28 per month per circuit, and $20 one-time installation charge per circuit.

Modems--$146 per month per pair of modems, and $200 one-time installation charges per pair.

Data Couplers--$16 per month per pair, and $20 one-time installation charge per pair.

Alternative Communication Approaches

We first observe that the average data rates from the instrumentation sites are expected to be quite low, the order of 10 bits per second. This can be contrasted with the 110 bits per second for 100-word per minute teletypewriter service, or the 1000 bits per second easily obtainable over leased or dial-up circuits.

Conceptually and technically, the simplest communication arrangement would provide a leased circuit from each data collection site to the central computer site. The poor utilization of the line, 1%, indicates that this may not be the most economical arrangement, however. Experience has shown that one can effect a trade-off between communication volume (and speed) and equipment complexity; pending an examination of that trade-off, we cannot dismiss this one circuit per site approach.

A second approach would tie several sites, perhaps 10 or more, to one single leased circuit that threads its way across the area (several such circuits might be needed). By suitable additional equipment at each site and at the computer site, the several sites could effect a sharing of the one circuit. With this technique, the utilization of the circuit could be substantially increased, and the number of circuit miles substantially reduced. Because of the additional costs of the additional equipment, such an approach is most beneficial when applied to sites distant from the computer site. An operational concern with this approach is reliability, in that a circuit malfunction, or a severe site malfunction, could disable all data-gathering activities for all stations on the affected circuit. Where repair times, primarily of the circuit, may be long (days to tens of hours may not be uncommon), this could be serious.

A third approach would have the computer periodically dialing each site. This is the most complex technique thus far considered, and the least examined. Cost economy is potentially possible here but, until the actual values are ascertained, we can only talk in generalities. In the Bay Area, a dialed call may cost on the order of $172.80 per mile per month; this is equivalent to $0.04 per call, plus $0.004 per mile per minute. Strong nonlinearities tend to reduce the cost per mile as the distance increases. If the circuit is fully utilized when in use, then it need be occupied on 0.01 month per calendar month, at best, thus the equivalent cost can be considered to be $1.73 per mile per calendar month, which is competitive with $3 to $4 per mile per month for a lease. Additional costs to be considered, however, are those of the automatic dialing and calling units, plus other auxiliary equipment. Dialed connections, we should also note, should prove to be more reliable than the leased, for with dialed connections a multiplicity of circuits is usually available to set up a call.

Chapter XIV

MIXING LAYER OBSERVATION PROGRAM

Introduction

Air quality and meteorological measurements made at the ground-based instrument stations provide atmospheric vertical profile data within the surface layer. However, both meteorological and air quality data will also be required above the surface extending through the mixing layer to a level on the order of one kilometer. These measurements, as well as specially designed procedures to support specific research experiments, will be required on a periodic and repeating basis similar to the ground-based operational scheme.

This chapter provides a discussion of the mixing layer observation program and presents several sets of concepts and recommendations for its development. The first covers instrumentation platforms suggested to function as the primary observational system and includes a helicopter for air quality measurements and the balloon-tracking system known as METRAC for meteorological measurements. The second set discusses special aircraft-based meteorological observations and their required instrumentation. The third set of concepts and recommendations covers the development of aircraft instrument packages with emphasis on air quality instruments. The last set reviews the current and anticipated future capability of the Western Environmental Research Laboratory (WERL) to conduct airborne air quality and meteorological observations and their potential involvement in the Regional Study.

General Mixing Layer Observation Methods

Two general methods can be employed for the acquisition of mixing layer measurements. The first includes the use of manned fixed-wing aircraft or helicopters, and the second covers balloon-borne systems. The characteristics of these two types of measurement systems are, of course, markedly different and each system tends to offer selected advantages and disadvantages, depending upon the nature of the measurement to be made. In the case of meteorological observations, for example, the advantages and drawbacks of aircraft measurements are fairly well known. To sum a few of the more important considerations, it should be recognized that control of the measurement platform is a distinct advantage. Measurements can be made at the desired location and can be repeated in short order. On the other hand, the accuracy of the wind measurements in particular is open to some question because of aerodynamic effects, and, equally important, the operating costs of the system are quite high. As such, it seems that use of aircraft would be highly desirable for special, short-duration meteorological research studies, but perhaps not for daily operation.

The collection of meteorological data by balloon techniques, on the other hand, is restricted to the more-or-less uncontrollable trajectory of the balloon. This can be an advantage when studying Lagrangian or air parcel processes, but is a disadvantage when objective cross sections of Eulerian conditions over the region are desired. Some flexibility is introduced in the use of both rising and constant level balloons, especially if it is possible to track simultaneously several balloons of one or both types. In this manner, one could observe the vertical structure of the atmosphere at several locations while also observing the nature of wind trajectories over the region at various altitudes and/or geographical locales. Operating costs can differ widely among various balloon systems and may this be an advantage for one and a drawback for another. These considerations have led to the recommendation that a newly developed balloon-borne instrument system known as METRAC be seriously considered for the Regional Study to provide routine, upper-air meteorological data. Aircraft or helicopters would be utilized primarily for air quality measurements alone on a routine basis, although the use of either for special meteorological observations is encouraged.

The selection between a fixed-wing aircraft and a helicopter for air quality measurements depends upon the number of factors with the choice significantly affected by the instrumentation package to be carried. Fixed-wing aircraft offer several advantages over helicopters as a means of making airborne measurements. The typical vibrations encountered aboard a helicopter are of low frequency and large amplitude, making isolation of vibration-sensitive instruments very difficult. Shock-mounting techniques are most effective against the higher frequency, small amplitude vibrations encountered in fixed-wing aircraft. In addition, considerable forward speed must be maintained in a helicopter to obtain air quality samples uncontaminated by the helicopter exhaust products in the downwash. The distinctive, annoying sound produced by helicopters in low level flight may result in frequent complaints when overflying populated areas. Conversely, fixed-wing aircraft are subject to more constraints when overflying urban areas than are helicopters.

The use of a helicopter as both an airborne laboratory and logistical support for emergency servicing of remote monitoring stations makes the rotary-wing aircraft an attractive choice. In addition, vertical profile, air quality measurements are more easily achieved over a fixed point with a helicopter than with conventional fixed-wing aircraft. On these bases it is recommended that a helicopter serve as the primary platform for an airborne laboratory. Support of routine helicopter operations could quite likely be provided by WERL during the execution of large field experimental programs. The expected increase in the capability of WERL over time, as discussed later, should prove to be a significant resource of the EPA, and its use in the Regional Study for the support of special programs should be of great value.

Primary Aircraft Support for the Regional Study

At least three important tasks can be defined for the use of aircraft in support of the ground-based activities that comprise the major work to be performed during the Regional Study. These are

(1) Logistic support during all phases of the research program

(2) Design, acquisition, testing, and operation of appropriate instrument packages in support of selected research experiments.

(3) Conduct of selected air quality and possibly meteorological research studies that require relatively sophisticated instrumentation and techniques.

The first two of these tasks should be initiated during the first six months of the program. It is recommended that a helicopter be acquired as a fixed cost to the research facility, and that operational costs be included during the life of the Regional Study. It is suggested that the third task be undertaken in collaboration with WERL, Environmental Surveillance Division. Mechanisms for allocation of aircraft, equipment, and personnel from WERL to the Regional Study should be specified by memorandum of understanding issued by the appropriate EPA office and acknowledged by WERL.

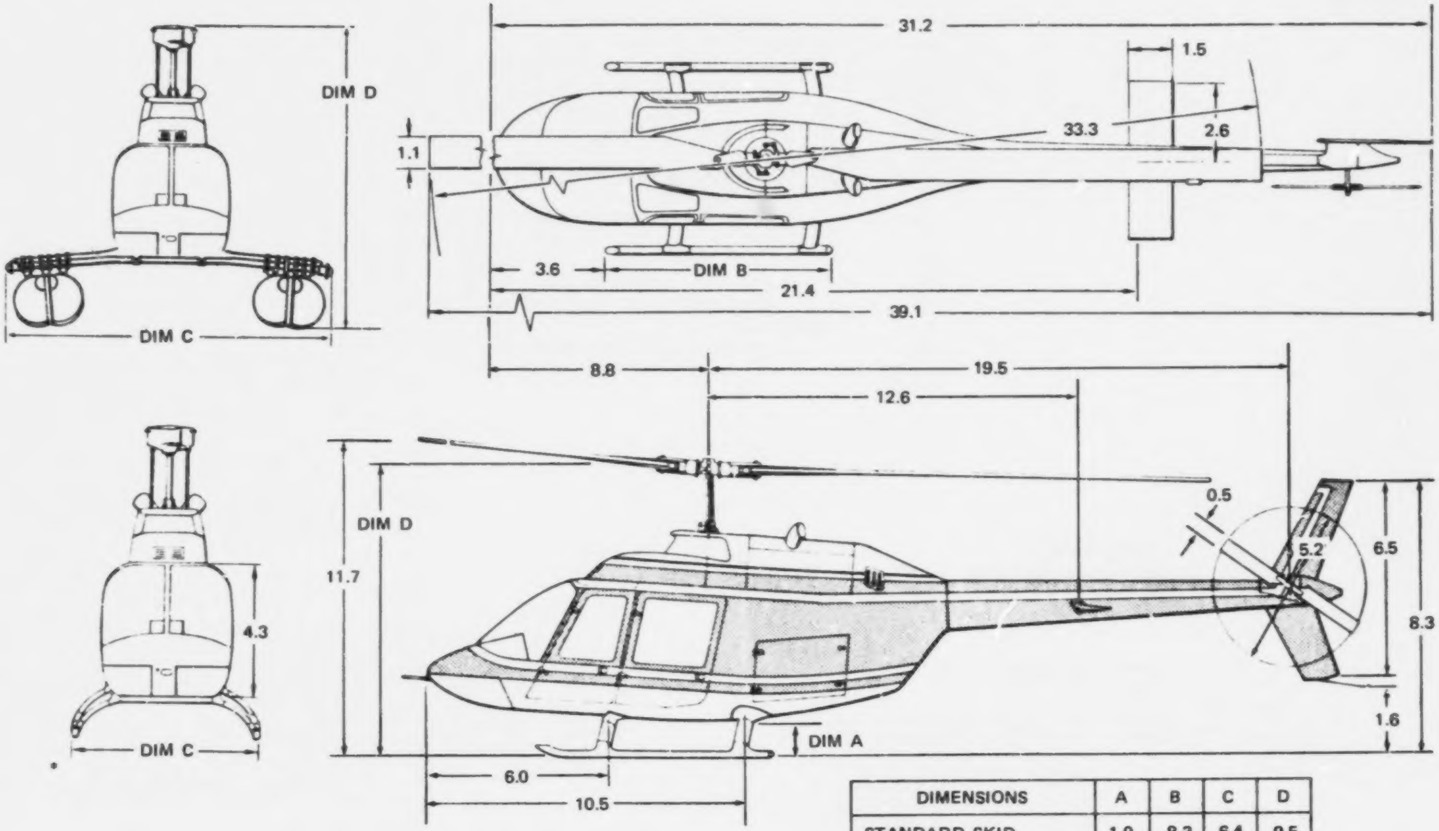
To accomplish the above and related tasks, two major systems need to be defined--a medium-sized helicopter with appropriate performance characteristics, and a fixed-wing aircraft to support planned upper air quality and meteorological studies. The helicopter is specified in terms of commercially available equipment that can accommodate a medium-sized instrumentation package subsystem. The fixed-wing aircraft and operating personnel can be provided by WERL. Integration of the WERL aircraft with the air quality and meteorological subsystems defined by the Research Plans can proceed concurrently with implementation of the ground station network.

Helicopter Support Function

The Regional Study provides a unique opportunity to critically examine airborne monitoring concepts and systems under controlled conditions. Moreover, the large scope of the study in terms of ground stations, personnel, equipment, and geographical coverage provides a reasonable justification, if not a logistic requirement, for aerial support. The versatility of a helicopter makes it ideally suited to provide emergency support in consideration of the number of ground stations that will require maintenance, calibration, and other functions. To provide sufficient capability to transport personnel, equipment, and an airborne instrument package, a medium-sized helicopter is recommended. The Bell Jet Ranger (Model 206B), or its equivalent, is considered to meet the requirements of the Regional Study. In comparison with smaller craft, the Jet Ranger offers an increased work area, it is less restrictive as to weight and balance or total load weight, and it provides more power for faster surveys, yet has the landing advantages of the small models. Additional factors include a reasonable fuel capacity and range, and availability of 110 to 115-volt outlets without the necessity for conversion from a 12- or 24-volt system. General features of the Jet Ranger are indicated by Figures XIV-1 and XIV-2 and by Table XIV-1. A sample weight calculation is shown by Table XIV-2.

Schedule of Operations

The scheduling of helicopter operations will vary to some extent depending upon the schedule of research experiments, weather conditions, and helicopter maintenance requirements. In general, more frequent and longer operational periods would be expected during active experimental programs in the spring-summer season than in the winter months. Major maintenance could be scheduled during the less active winter season. For planning purposes here, the operational schedule will be assumed to include 18 hours per week during the period March through October and 12 hours per week for the balance of the year. Thus a total of approximately 830 hours of operation could be expected.



DIMENSIONS	A	B	C	D
STANDARD SKID	1.0	8.3	6.4	9.5
HIGH SKID	1.9	8.3	6.8	10.4
STANDARD FLOATS	2.2	13.4	11.5	11.0
EMERGENCY FLOATS	2.1	10.9	8.8	10.5

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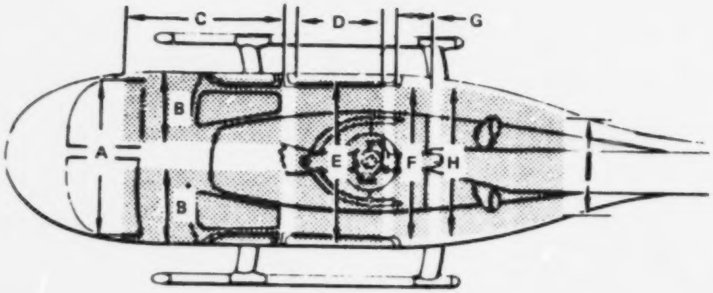
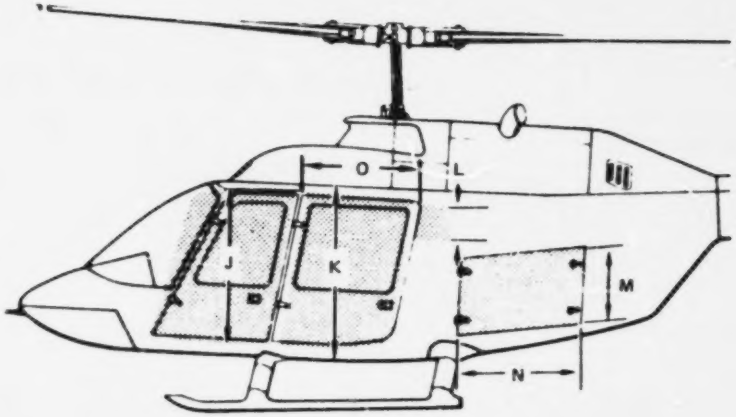
FIGURE XIV-1 EXTERNAL FEATURES OF THE JET RANGER MODEL 206B



MAIN CABIN CARGO SPACE
APPROXIMATELY 40 CUBIC FEET



BAGGAGE COMPARTMENT
16 CUBIC FEET

	FEET
A. FORWARD CABIN WIDTH	4.0
B. FORWARD SEAT-WIDTH (each)	1.3
C. - AND LEG-ROOM	3.6
D. AFT SEAT- AND LEG-ROOM	3.3
E. -WIDTH	3.9
-TO FLOOR	1.0
-TO ROOF OF CABIN	3.3
F. BAGGAGE SHELF-WIDTH	3.4
G. -DEPTH	0.8
H. BAGGAGE COMPARTMENT-FWD WIDTH	3.4
I. -AFT WIDTH	1.6
J. DOOR OPENING HEIGHT	3.8
K. CEILING TO FLOOR	4.3
L. BAGGAGE SHELF HEIGHT	1.3
M. BAGGAGE COMPARTMENT-HEIGHT	1.8
N. -LENGTH	3.0
O. AFT DOOR OPENING-WIDTH	2.9

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FIGURE XIV-2 INTERIOR DIMENSIONS OF THE JET RANGER MODEL 206B

Table XIV-1

WEIGHT, PERFORMANCE, AND POWER RATINGS FOR THE JET RANGER MODEL 206B

WEIGHTS:	LB
*F.A.A. empty wt	1455
Basic configuration wt (F.A.A. empty wt + usable oil)	1466
†Standard configuration wt	1515
F.A.A. normal gross wt	3200
F.A.A. external load gross wt	3350
Max useful load (gross wt - F.A.A. empty wt)	1745
Conf useful load (gross wt - std conf wt)	1685
Max external load	1200

* The 206B empty weight includes 70 pounds for 5-place upholstered interior with cushioned seats, soundproofing, rug, and seat belts.

† The 206B standard configuration weight includes 29 pounds of additional standard accessories not included in the empty weight plus 11 pounds of usable oil and 20 pounds of ballast (allowance for avionics).

PERFORMANCE: (Standard Day)

Take-off, gross wt		2200	3000	3200
I.G.E. hovering ceiling (2 ft skid ht)	ft	20,000	13,000	11,300
O.G.E. hovering ceiling	ft	17,800	8500	5800
Certificated altitude	ft	20,000	20,000	13,500
Service ceiling (TOP)	ft	20,000	20,000	13,500
Service ceiling (MCP)	ft	20,000	19,000	13,500
Sea level max rate of climb (TOP)	ft/min	2730	1540	1260
Sea level vert rate of climb (TOP)	ft/min	2160	690	280
Max allowable A.S. (at 5000 ft)	mph	153	153	134
Max allowable A.S. (at sea level)	mph	150	150	140
Max cont cruise A.S. (sea level)	mph	142	136	133
‡Range cruise A.S. (sea level)	miles	365	350	345
Max cont cruise A.S. (5000 ft)	mph	145	138	138
‡Range cruise A.S. (5000 ft)	miles	417	393	383

‡ 7 lbs fuel allowed for warm-up and take-off but no reserve.

POWER RATINGS

Engine (Allison 250-C20)	
Take-off horsepower, SHP	400
Max continuous, SHP	346
Airframe ratings	
Take-off horsepower, SHP	317
Max continuous, SHP	270

FUEL

Type	Aviation turbine
Capacity	76 gallons

Table XIV-2

SAMPLE WEIGHT CALCULATION FOR JET RANGER MODEL 206B

Configuration Weight

	Weight in lb
Weight empty	1455
* Engine oil (usable)	11
* Flap restraint	3
* Night lighting	10
* Door locks	1
* Hour meter and clock	2
* First aid kit	1
* Fire extinguisher (cabin)	8
* Fuel filter kit	4
* Ballast or equipment allowance	20
Total configuration weight	1515

Mission Weight

Standard configuration weight	1515
Pilot	170
Full fuel	494
Passengers (4)	680
Baggage	250
Additional payload or equipment	91
Total (gross weight)	3200

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* Accessories, kits, included in standard configuration.

Costs

A general breakdown of estimates for direct and fixed costs is provided by Table XIV-3. Certain additional costs will need to be evaluated in terms of the actual conditions found to exist in the St. Louis area; these include rental costs for ground space at an airport and provisions for helistop areas near some ground stations. Helistop pads will require essentially the same road access and local approval as the ground station. A 100-foot diameter area is suitable, assuming the absence of tall buildings or other obstructions in the vicinity of the pad. Both the direct and fixed costs are developed on the basis of an hourly cost of operation. The principal components of the costs of direct operation include consumables: fuel and lubrication, maintenance, labor, and parts. Direct costs are estimated at $45.12 per hour of operation.

Estimates of hourly operating costs derived from fixed costs require assumptions concerning depreciation, insurance, pilot salary, and annual flight hours. Values for depreciation and insurance are based on an assumed helicopter configuration with a list price of $150,000. A depreciation schedule is assumed such that the helicopter will have a 30% residual value at the end of five years. The total hourly fixed cost is estimated at $56.62. The total annual estimated costs are shown in Table XIV-4 under the assumption of 830 hours of operation per year. Annual costs average $84,400, with five-year costs at $422,000.

Helicopter Instrumentation Package

The airborne instrumentation complement should include both air quality and meteorological instruments. The basic instrument complement would be installed as a package in a helicopter for measurements to be made on a routine or a scheduled basis. The recommended meteorological parameters to be measured on a routine basis would be dew point, temperature, and ground surface temperature. Moisture measurement techniques are probably less satisfactory and less well advanced in the state of the art than most other meteorological instrumentation techniques. Several types of moisture analyzers are commercially available based on different moisture measuring techniques. The most common techniques are based on (1) an electrical resistance change as a desiccant material absorbs moisture, (2) condensation of moisture on a mirror at a known temperature, and (3) absorption of moisture by a desiccant deposited on an oscillating quartz crystal. Of these techniques, the one best suited to airborne operation would be a dew point hygrometer based on change in reflectivity as moisture condenses on a mirror. This technique has been used successfully in airborne operation by NCAR.

Table XIV-3

DIRECT AND FIXED COSTS FOR HELICOPTER SUPPORT FUNCTION

Direct Cost of Operation

Consumables		Cost/hr
Fuel - 25 gal/hr at 30¢ gal	7.50	
Lubrication - grease and oil/hr	0.18	
		$ 7.68

Maintenance labor

Airframe maintenance man-hours

Periodic Insp	Required per 1200 hr	Approx M/H ea	Total M/H
100 hr	11	8.0	88.0
1200 hr	1	128.0	128.0
Unscheduled maintenance estimate			87.0

Engine maintenance man-hours

Scheduled and unscheduled maintenance	150.0
Total maintenance man-hours	453.0

$$\text{Labor cost} = \frac{453 \text{ M/H} \times \$6.00 \text{ hr}}{1200 \text{ hr}} = \qquad 2.27$$

Allowance for airframe spare parts

Replacement at scheduled inspections	$0.37	
Replacement at overhauls	3.29	
Unscheduled replacements	0.98	
Replacement of retirement parts	6.03	
		10.67

Table XIV-3 (Concluded)

	Cost/hr
Allowance for engine spare parts	
Replacement at scheduled inspections and unscheduled replacements	$ 1.50
Allowance for engine overhaul	
Based on 1000 hr TBO (price estimated at $13,000)	13.00
Allowance for contingencies	
Primarily experimental functional modifications	10.00
Total direct cost per hour	45.12
Fixed Cost of Operation	
Fixed cost on annual basis	
Depreciation	
An equal apportionment over 5 years is assumed with a 30% residual	$21,000
Insurance	
Direct government operation would imply self-insurance; for illustration, however, 8% of the list price is assumed based on private operator experience	12,000
Pilot	
Average salary experience	14,000
Total	47,000
Total fixed cost per hour	56.62

Table XIV-4

HELICOPTER SUPPORT FUNCTION
TOTAL COST OF OPERATION
(830 Hours per Year)

Hourly direct costs	$ 45.12
Hourly fixed costs	56.62
Total hourly costs	101.74
Total annual costs	84,400.00
Total five-year cost	422,000.00

The measurement of temperature does not present any particular problem for airborne operation. Therefore, either the commercial Rosemount probe or the technique used by NCAR for airborne operation would be recommended.

Ground surface temperature is measured through the use of an infrared radiation measurement. A simple narrow-field bolometer would permit mapping of the surface radiative temperatures.

The space and weight restrictions of the airborne laboratory platform limit the number of pollutants that can be monitored on a routine basis. The pollutants that are recommended for routine monitoring would be sulfur dioxide, carbon monoxide, ozone, and atmospheric turbidity. Sulfur dioxide monitoring is recommended for several reasons. First, it is a pollutant of considerable interest. As it will be studied extensively within the reactive chemistry program, the additional data concerning its vertical distribution and transport will be of great value in the development of atmospheric models. The concentration of sulfur dioxide within the ambient rural atmosphere will be significantly lower than the concentration anticipated within the plume of St. Louis, but, even at 100 kilometers downwind, the boundaries of the plume can be defined through airborne measurements. The airborne measurements of carbon monoxide will be used to indicate dilution processes within the plume of St. Louis. The ozone measurement and atmospheric turbidity will be used as an indicator of photochemical activity and general air quality within the flight patterns.

The research project to design an instrument package for use aboard a helicopter must evaluate the available pollutant monitors to determine those measurement techniques that are most suitable for this application. The monitoring techniques should be evaluated on the basis of speed of response, size and weight, power requirements, type of reagent required (gases, liquid), sensitivity to vibration, and safety in airborne operation. The constraints of airborne operation are such that techniques not recommended for the ground-based monitoring network may prove to be the most suitable for airborne measurements.

A preliminary recommendation of air quality monitors, based on the constraints of airborne service, and subject to a more detailed examination in the evaluation research project would be as follows:

Total sulfur gases - flame photometric detection

Carbon monoxide - mercury displacement

Ozone - ultraviolet absorption.

The sulfur dioxide monitor based on flame photometric detection may not be feasible due to safety considerations of an open flame during flight. However, if the flame is extinguished during take-off and landings, this may be an acceptable procedure. The use of an on-board hydrogen generator with a limited production capacity could be substituted for a compressed hydrogen cylinder. The stability of the flame during airborne operation should be evaluated to determine if adequate detection sensitivity is maintained. A second choice for sulfur gases would be a microcoulometric detection technique, which uses liquid reagents instead of flame photometric detection.

The mercury displacement technique is recommended for the measurement of carbon monoxide for several reasons. Through modification of available instrumentation, a monitor of adequate sensitivity for rural concentration of carbon monoxide can be obtained. In addition, size and weight are suitable for airborne operation.

The ultraviolet absorption technique recommended for ozone is primarily based on the elimination of the reagent ethylene as is required by chemiluminescent ozone monitors. A second choice would be the electromechanical technique for the measurement of ozones.

The airborne data acquisition system should record the measurement by an on-board digital recorder in a format compatible with the central data archives of the ground-based monitoring network. Calibration of the equipment can be made on the ground prior to and after surveillance flights.

Balloon Tracking System

A balloon system designed primarily for meteorological observations that appears to have especially high potential is known as METRAC and previously known as DILOSONDE. The METRAC system is currently a proprietary system under final development by the Control Data Corporation.

System Design Concept

METRAC employs Doppler tracking techniques to determine a highly accurate three-dimensional position of an inexpensive radio transmitter. This light weight transmitter, carried either on a rising or horizontally floating small balloon, permits fine-scale measurements of the wind, and as many as four measurements from additional sensors on the balloon. Radio signals are received by a minimum of four portable ground stations, and the information is relayed by radio or landline communication to a central data terminal. The data are then recorded for future use or processed immediately by a small computer.

Primary METRAC advantages are low cost and high accuracy. Flight packages are expendable, as in radiosondes, and the cost is comparable or less. Ground station designs are much less complex than the usual instrumented towers, rawinsonde sounding system, or radar-positioning system. The master station is fully automated and the only operator requirement is starting the receivers before launch. As data generated by the master station are formatted for direct computer processing, no intermediate processing preparation is required. A small computer can process an entire profile in less than five minutes. The high accuracy in three-dimensional positioning permits detailed calculation of resultant winds. This high resolution of data in time and space thus enables the determination of small-scale features of vertical or horizontal profiles. Several other advantages are basic to the system. By using a network of these systems, the inherent accuracy and range is limited only by the boundary of the network. Thus tracking over hundreds of kilometers is possible as long as at least four receivers remain in radio line-of-sight. Observations can be taken day or night in all weather conditions. Simultaneous tracking of multiple balloons is possible with special modification of the system. Finally, the flexibility provided by the multisensor capability should not be underestimated. Simultaneous point measurements (gradient values if more than one balloon is tracked) of wind, temperature, humidity, pressure, and net radiation can be obtained at precisely determined locations.

The determination of space coordinates at any instant of time is based upon the system's ability to monitor differential Doppler shifts between the received frequencies at the various ground-based receivers. At each ground station, a receiver translates both the NBFM telemetry information and its Doppler frequency shift from a radio frequency carrier to an audio-frequency carrier signal, which comes unmodulated from the central data terminal. This data-carrying signal from each receiver is then transmitted to the central data terminal via a voice channel communications link.

While a minimum of four ground stations is required, it is recommended that seven stations, arranged in a hexagonal pattern with one in the center, be used in order to provide some redundancy and thereby reduce the vulnerability of the system to equipment failures or multipath and other propagation effects. Use of seven stations allows the calculation of 35 coordinate positions for the mobile transmitter at any given instant. Should propagation problems affect the signal at one ground station, a total of 15 coordinate positions is available; whereas if the signals at two of the ground stations are affected, a total of five coordinate positions is still available.

At the data terminal, the signal from each ground station is sampled a minimum of 50 times per second. This high rate is necessary to recover the telemetry data even though the modulation deviation is low. Each balloon-borne sensor is sampled once each second; however, 50 positions per second may be computed if this fine a time scale is desired. Ordinarily, and especially in on-line computing, it is not desirable to obtain position information at this rate, and digital filtering of the data may be advantageous.

Indications are that the use of a six-balloon METRAC system could provide six 15-second averages of vector winds every 15 seconds with a resolution of better than 0.1 m/sec. Winds for a one-second average (single balloon) can be resolved to 0.3 m/sec. Therefore, the system is capable of resolving the vector velocity of the balloon to a degree equal to or better than the representativeness of the balloon in describing the ambient wind fields. As a comparison of alternate optical and radio tracking techniques, the following table from the HMSO Handbook of Meteorological Instruments (1961) is presented below. (Table XIV-5)

The ground-based receivers are housed in light-weight weatherproof packages and can be mounted on a 10-foot pole that is used to support the receiver antenna system. The pole itself is sectioned for easy portability and is supported by a guy system that also functions as a reflecting screen for the antenna. The antennas are simple and stationary since the use of directional arrays is not required.

Table XIV-5

VECTOR ERROR OF WIND (m/sec) AT 5 km AS A FUNCTION OF TRACKING SYSTEM AND RATIO (Q) OF MEAN WIND TO ASCENT RATE

Q	A	B	C	D
1	0.5	0.5	0.5	1.0
2	0.5	1.0	1.0	2.0
3	0.5	2.0	1.5	3.6
4	1.0	3.6	2.5	5.1
5	1.0	5.6	3.6	7.1

A - Radar
B - Optical or radio-theodolite and radiosonde height
C - Double theodolite or direction finder
D - Optical or radio-theodolite and assumed ascent rate.

Simultaneous tracking of more than one balloon requires equipment to be added at both the receiver and data terminal sites in addition to the use of separate transmitting frequencies for the mobile transmitters. Each receiver will require an additional IF unit for each channel used as well as a multiplex unit for the data link. A multiplex adapter will also be needed at the data terminal unit in addition to either a high speed incremental tape unit or a high speed data transmission link to a computer.

Apart from the high-resolution features of METRAC, the flexibility of the system is particularly attractive. For example, it would be extremely valuable to have the capability to collect simultaneously five or six vertical soundings throughout the study region at, say, a one-hour periodicity during intensive model test periods or, say, four-to-six per day (perhaps at fewer locations) on a routine basis. The coincidental measurement of wind trajectories over the region would also provide necessary meteorological data. With a system such as METRAC, both programs could be undertaken simultaneously or perhaps the vertical soundings could be interspersed in the horizontal tracking program.

Activation Schedule

The basic METRAC system has been tested on a limited basis but the system developers have estimated that an additional six-month preliminary design and test period is required for implementation as an operational system. This program would evaluate and resolve design criteria for particular space and time scales (resolution), available radio frequencies, and sensor requirements.

If the METRAC proves successful after the six-month test period, it is estimated that one year will be required to finalize software and station design, fabricate the system, and complete installation and acceptance tests. Thus, a total of 18 to 24 months is estimated subsequent to authorization of the Regional Study to bring the METRAC system to full operational status.

Costs

The costs of the METRAC system will vary to a limited extent with the number of ground stations and the number of balloons which the system can simultaneously track. For example, a single balloon tracking capability having six remote stations and one central station is estimated at $395,000, whereas a six-balloon tracking capability with 18 remote and one central station is estimated at $476,000. Both estimated costs include final development costs of $100,000. Table XIV-6 provides these estimated costs in greater detail. For the St. Louis region approximately 18 slave stations would be required to adequately track up to six balloon instrument packages simultaneously within a 350-km radius. Remote station costs for a single-balloon system would be approximately one-half the six-balloon system.

The METRAC system operating costs have been estimated at approximately $8000 per balloon release location per month for the weighted manpower costs of an intensive round-the-clock operation with all data processing completed in real time. This cost compares favorably with the NOAA radar-tracking tetroon system, for example, which is estimated to incur costs up to $100,000, for a one-month intensive period of operations and subsequent data processing.

Table XIV-6

ESTIMATED INITIAL COSTS OF THE METRAC SIX-BALLOON SYSTEM
(Thousands of Dollars)

Preliminary design and test	$100.00
Final design, fabrication, installation	250.00
Central station	50.00
Remote stations at $2	36.00
Computer	40.00
Total	$476.00

Special Aircraft-Based Meteorological Observations

General Concepts

While the proposed balloon-tracking system will provide upper-air meteorological observations on a routine basis as well as in conjunction with some special programs, an aircraft-based meteorological observing system is also recommended for some of the special problems. In particular, the use of aircraft is desirable and almost necessary for studies of urban-rural radiation differences and basic studies of large-scale atmospheric turbulence structure in relation to regional, upper-level diffusion processes.

The intermittent sequencing of these special programs might require the use of several different aircraft. Existing operational systems maintained by other agencies, institutions, or firms might be brought in as necessary on either a cooperative or contractual basis. As an example, the flight facility at NCAR might be engaged through a cooperative arangement with their FAPS program (see Chapter VIII), or the aerial capabilities of NOAA or various university and private institutions could be solicited on a contractual basis. Alternately, WERL may recognize the task under their charter of responsibility and seek to expand their capabilities to undertake these tasks. Above all, the choice should be based on the ability of the party to provide the necessary meteorological data with a satisfactory resolution and processing time, as well as their ability to provide aircraft of sufficient size to accommodate air quality instrumentation.

Vertical and horizontal profiles of the mean wind are essential. Horizontal profiles should be obtainable on a distance scale on the order of five kilometers; vertical profiles to 1500 meters above ground level are anticipated. As part of the tasks of the detailed evaluation of gradient transfer diffusion models, turbulence measurements may also be required to compute eddy diffusivity values. If this is a major requirement, an inertial guidance system will be necessary rather than the more conventional Doppler system. Ambient air temperatures will be necessary for several programs; horizontal mapping of mean temperatures at several altitudes will be necessary for heat island and radiation studies, while high-frequency measurements will provide input to sensible heat flux computations for heat budget and gradient transfer studies. Dew point measurements are also advantageous for the aforementioned studies as well as investigations of urban precipitation modification and tall-stack plume rise phenomena. Radiation measurements that are required have been outlined in the earlier discussions of both meteorological and photochemical research tasks. Measurements should be made of the outgoing longwave radiation in the atmospheric "window" to permit mapping of the surface, radiative temperature. Space-averaged values from a narrow-field bolometer should be used to obtain the desired spatial resolution. Precision observations of the broad spectrum incoming direct and diffuse and the outgoing total (diffuse) shortwave radiation should also be made. Additionally, the capability for making spectral radiation measurements and collecting particle samples is also desirable.

In summary, there are three capabilities which a fixed-wing airborne system has over either rotary aircraft or balloon-tracking systems. First, airplanes provide a platform for making difficult turbulence and radiation measurements. Secondly, balloons may be capable of providing some of these data, but not with the positional flexibility of the airplane, and helicopters may have greater positional flexibility, but they cannot be effectively utilized for precision radiation measurements and can provide virtually no wind data. Thus, airplanes have a common "radiation advantage" and some "wind advantages" over the two alternatives, while providing positional flexibility only in comparison with balloons. These advantages are sufficient to warrant limited use of a fixed-wing system, but probably not on an extended basis.

Instrumentation Considerations

There is a long history and extensive literature concerning the use of aircraft as meteorological platforms. No attempt is made here to summarize this field. We note, however, that continuing aircraft programs exist at NCAR, at the research flight facility of NOAA, and elsewhere. Improved instruments are being developed by these groups.

The main problem in measuring meteorological variables from a moving aircraft is that conditions at sensor locations close to the aircraft are generally disturbed and are different from ambient conditions. Thus corrections must be made, or nose booms may be used as sensor platforms. For the Buffalo aircraft used at NCAR, the nose boom is five meters in length with a modified conical shape. It consists of an inner stainless steel circular boom or probe that is directly aligned with the inertial system, and an outer fiberglass shell which provides the airfoil shape as well as the housing for some of the other sensors on the craft.

Temperature can be measured with an absolute accuracy of approximately 0.5°F and a relative accuracy of 0.1°F. A well-known instrument is the commercial Rosemount probe. It is adequate for the low-frequency temperature measurements that need to be made for mesoscale analysis. Two other thermometers have recently been developed at NCAR. They are a reverse flow thermometer and a tungsten fine wire resistance thermometer. The latter gives very high resolution data for turbulence studies. Infrared thermometers are also being built. The Rosemount instrument is probably adequate for the St. Louis study.

For measuring atmospheric water vapor, aircraft dew point hygrometers are available from EG&G, Waltham, Massachusetts, that are accurate to 1°F, and sensitive to 0.1°F. This type of instrument should be quite suitable for the present use. For faster response data, a microwave refractometer is used at NCAR.

Pressure can be measured adequately using the aircraft altimeter or a special transducer. To measure horizontal pressure gradients, however, simultaneous pressure and radar altitudes must be recorded, and the height of the underlying terrain must also be known. For the relatively flat terrain of the St. Louis area, it should be possible to measure horizontal pressure gradients (geostrophic winds) with useful accuracy. It appears too that a measurement of the vertical pressure gradient can be obtained by comparing the radar altimeter readings with those of the barometric altimeter along a vertical axis.

The measurement of wind from an aircraft is difficult because the wind is deduced as a relatively small vector difference between two measured vectors: the ground speed vector (along the true course) and the true airspeed vector (along the true heading). Both Doppler and inertial navigation systems measure the ground speed vector and the drift angle. The main uncertainty in using either system for measuring winds is in the length of the true airspeed vector, which is difficult to measure with the same high precision achieved in measuring ground speed. The error in true airspeed causes a small uncertainty in the measured wind vector. For the NCAR Buffalo aircraft, a special true airspeed system has been installed to maximize accuracy. Such a system may add a precision of 1 to 2 m sec^{-1} to the true airspeed measurement. The NCAR system uses a set of vanes for the alignment of the pitot pressure sensor with the relative wind. This serves to decrease the error in pitot pressure introduced by side-slip of the aircraft. True airspeed is computed from pitot and static pressure, and temperature.

The Doppler and inertial systems have some significant differences which should be noted. The inertial system, built around accelerometers along three axes, is capable of very high response that makes it especially appropriate for use in measuring turbulence. The Doppler system is of much slower response and gives integrated values of ground speed over approximately 10 to 20 seconds. In contrast to the inertial navigator, it does not give a measurement of speed along a vertical axis. According to Dr. Donald Lenchow of NCAR, the inertial system (with the special true airspeed measurement) gives winds accurate to 1 m sec^{-1}, while a Doppler system has a comparable accuracy of 2 m sec^{-1}. Both of these values are better than the accuracy of standard rawinsonde measurements of winds. On the other hand, some experienced personnel at SRI do not agree that inertial systems are inherently more accurate than Doppler systems.

In further consideration of the two systems, the following operational aspects should be considered. The inertial system requires a 15-minute alignment time after takeoff, thereby increasing the total length of time of a projected flight. However, for operational considerations this 15-minute delay would probably not mean very much. The inertial equipment is more difficult to maintain than the Doppler; therefore two (or three) independent inertial units are normally combined in a single system for use on commercial aircraft. The inertial system cannot be turned on and off during flight unless the aircraft returns to a fixed position and initiates a second alignment procedure. The inertial system, however, is capable of operation at any height while the Doppler system will not operate at extremely low altitudes. This lower limit is on the order of 200 feet.

It appears that this potential height limitation in the Doppler system will not be of any serious consequence for its consideration in the Regional Study Program. The output from both the inertial and Doppler systems is of the following: position, ground speed, drift angle, true heading, and track.

In the inertial system these items are routinely determined once per second although higher resolution is possible. The inertial system comes with its own computer and display consoles and, with the measurement of true air speed, will also provide an output of the two horizontal components of the wind. Comparable components are available for Doppler equipment. The inertial system also provides one second output of vertical acceleration and, upon integration with respect to time, will provide the vertical component of the wind. In practice the vertical wind component is determined with the inertial system for frequencies less than 100 seconds and for the longer term mean wind (that is frequencies less than 1 every 100 seconds) a pressure altimeter measurement is used. To display the wind components an auxiliary computer is necessary. The computer must accept readings of the pitot, static pressures, and temperature to compute true air speed, as mentioned previously. This requirement for a computer is in reality of no great significance as it will always be highly desirable to have an onboard computer to preprocess the meteorological and air quality data being collected on the aircraft. The accuracy of the wind measurement with an inertial system is improved by use of frequent fixes on ground navigation points because of the so-called Schuler period of 84 minutes over which the inertial system has a sinusoidal drift. This drift, if uncorrected, will not permit the accuracy levels mentioned previously to be met.

In considering the relative merits of Doppler and inertial navigation equipment for the Regional Study, the following considerations should be borne in mind:

(1) The accuracy of the systems is approximately equivalent, but some authorities favor one system over the other.

(2) The inertial is a rapid response system and is much more suitable for turbulence measurements, if these are needed.

(3) Both systems are small and compact.

(4) The costs of an inertial system are approximately double those of Doppler equipment.

(5) The inertial system requires alignment at the beginning of a flight.

If it is decided that the aircraft should be capable of providing both average and turbulent wind conditions along the flight path, then selection of inertial equipment is favored. However, if high frequency data are not needed routinely, the decision should not be made without a careful engineering evaluation of the factors mentioned above.

In meteorological flights made with the NCAR Buffalo aircraft, altitudes as low as 500 feet have been followed at speeds between 140 and 160 knots. This range provides a safe flying speed as well as maximum resolution in the wind and temperature measurements. That is, from a safety standpoint, it is desirable to fly above a minimum speed, while for the measurement of high frequency meteorological parameters and in consideration of the sources for measurement errors it is desirable to fly at the lowest possible speed. The indicated speed range represents a compromise on the two considerations.

In using aircraft to measure vertical profiles of meteorological variables, they can be flown in spirals with a 360° turn in two or three minutes, and a rate of climb (or descent) of approximately 1000 feet per minute. The diameter of the spiral would be approximately three to five miles. The Doppler system can accommodate this type of maneuver, and the inertial system will function in even tighter turns.

Projected long-range flights by the aircraft for monitoring around the Regional Study area will probably have to encompass a circular grid having a diameter of approximately 120 kilometers. Therefore, if one defines a relatively square pattern to be flown about the area, each leg of the flight would probably have a length on the order of 80 nautical miles. It will be desirable to make routine flights at a minimum of two different altitudes within as short a time period as possible. It will also be necessary to make vertical profile measurements with the aircraft at different times and at different locations in the grid.

The data, in summary, that would result from such a flight program would include spiral measurements (vertical profiles) at upwind and downwind locations on the grid as well as the measurement of the vertical and horizontal wind structure around the perimeter of the grid at one or more heights. The program will also provide some input on temporal variations in the wind flow field. Such variations will further be indicated by frequent (perhaps three-hourly) low level balloon measurements within the grid.

Various flight plans will be desirable for special programs. One purpose might be to sample along the general flow direction at several altitudes, with the path extending both upwind and downwind from pollution sources. A flight which starts at a given altitude on one side of the city could be made to the opposite point where the altitude is changed, and the route is traversed in the opposite direction. This would provide data for cross-sectional analysis; for example, along the axis of a plume of effluent. Other flight programs will be dictated by the requirements of the special research studies.

Special Aircraft-Based Air Quality Observations

The fixed-wing airborne laboratory recommended for special meteorological observations can serve as a vehicle for nonroutine air quality measurement of nitrogen oxides, aerosol particles size distribution, and total particulates. The recommended monitors for the nonroutine air quality measurements should be quite suitable for airborne operation and are as follows:

Nitrogen oxides - chemiluminescence

Particle size distribution - Royco-type particle counter

Total particulate - filter collection.

If space limitations aboard the fixed-wing aircraft are not severe, the entire air quality instrument package used in the helicopter could be installed on a temporary basis in fixed-wing aircraft in addition to the nonroutine air quality instrumentation. The data acquisition system used aboard the NCAR Buffalo Aircraft, for example, may not be compatible with the RAPS system. However, the infrequency of flights would make the manual transfer or transcribing of data to the appropriate format a feasible procedure.

Western Environmental Research Laboratory (WERL)

The current and planned airborne monitoring capability of the WERL represents an important potential resource for the Regional Study. WERL currently operates several aircraft instrumented for detecting and tracking airborne and ground-deposited radioactive particles. The aircraft are also fitted with a variety of sampling systems which have application to a broad range of radioactive and nonradioactive air pollutants. A staff with up to ten years' experience in aerial surveillance provides personnel with the ability to perform diverse functions in this field. Current objectives include (1) acquisition of additional equipment and personnel to provide aerial surveillance services, (2) provision of aerial surveillance of air, water, and terrestrial pollution and pollution effects to requesting offices in EPA, including collection, interpretation, and reporting of data, and (3) maintenance of equipment and personnel capability to respond to environmental crises which might occur any place in the nation.

WERL currently plans to make available to the Regional Study, as required, one fixed-wing aircraft, one helicopter, and appropriate operational and maintenance staff. WERL aircraft will eventually include the following:

- Two each Mohawk aircraft (A)-OVIB and (B)-OVIC*
- One T-34
- One C-45
- One C-123
- Two each Huey Model P, 11-place helicopters (200-minute flight time with 15-minute reserve time with speeds up to 140 knots).

The C-123 will be able to transport an experimental team and mobile laboratory to distant sites, if required. ESD's analytical and sensing hardware is at present limited to particulate sampling, radiological monitoring, and aerial photographic equipment.

The ESD staff foresees a need to be prepared for a full range of environmental problems and to offer support to other EPA divisions in pollution-control monitoring, enforcement, and research, and is beginning to assemble the remote-sensing, sampling, analytical, and information-processing equipment to perform this broad range of functions. The Regional Study will provide an opportunity to assemble an air quality surveillance system that is based on demonstrated needs as defined by the upper air meteorological and air quality research plans. The system will be composed of subsystems that have specific functions and requirements. The surveillance system functions will include the following:

(1) Selection of environmental parameters

(2) Selection of surveillance techniques

(3) Data collection

(4) Data recording, processing, and analysis

(5) Dissemination to project personnel and other users.

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* Two-place Army observation plane. Two turboprop engines, 2500-pound payload, top speed 300 mph at 4000-foot altitude. Maximum range with external tanks-1400 miles.

Effective execution of each of these functions will depend on a number of elements, including skilled personnel, appropriate technology, and efficient organization. This set of interrelated functions must be carried out in a unified, balanced manner if the system is to be productive in terms of project objectives.

A generalized and simplified picture of systems interrelationships in the aerial surveillance program is presented by Figure XIV-3, in which the approach to air quality surveillance is outlined.

Selection of Parameters

Selection of the type of data to be collected is critical to any program that aims to improve project operations in a significant way. It is important to choose parameters that are directly related to the goals to be attained. It is also necessary to consider surveillance techniques in selecting parameters. Deciding on where and when to sample or measure and what quantity of data is desirable are critical questions that are inextricably tied to the design of the data-collection subsystems. The desired parameters with respect to meteorology and air quality are discussed in Chapters XI and XII, as well as throughout Part II, and provide the key factors for initiation of systems integration.

Selection of Surveillance Techniques

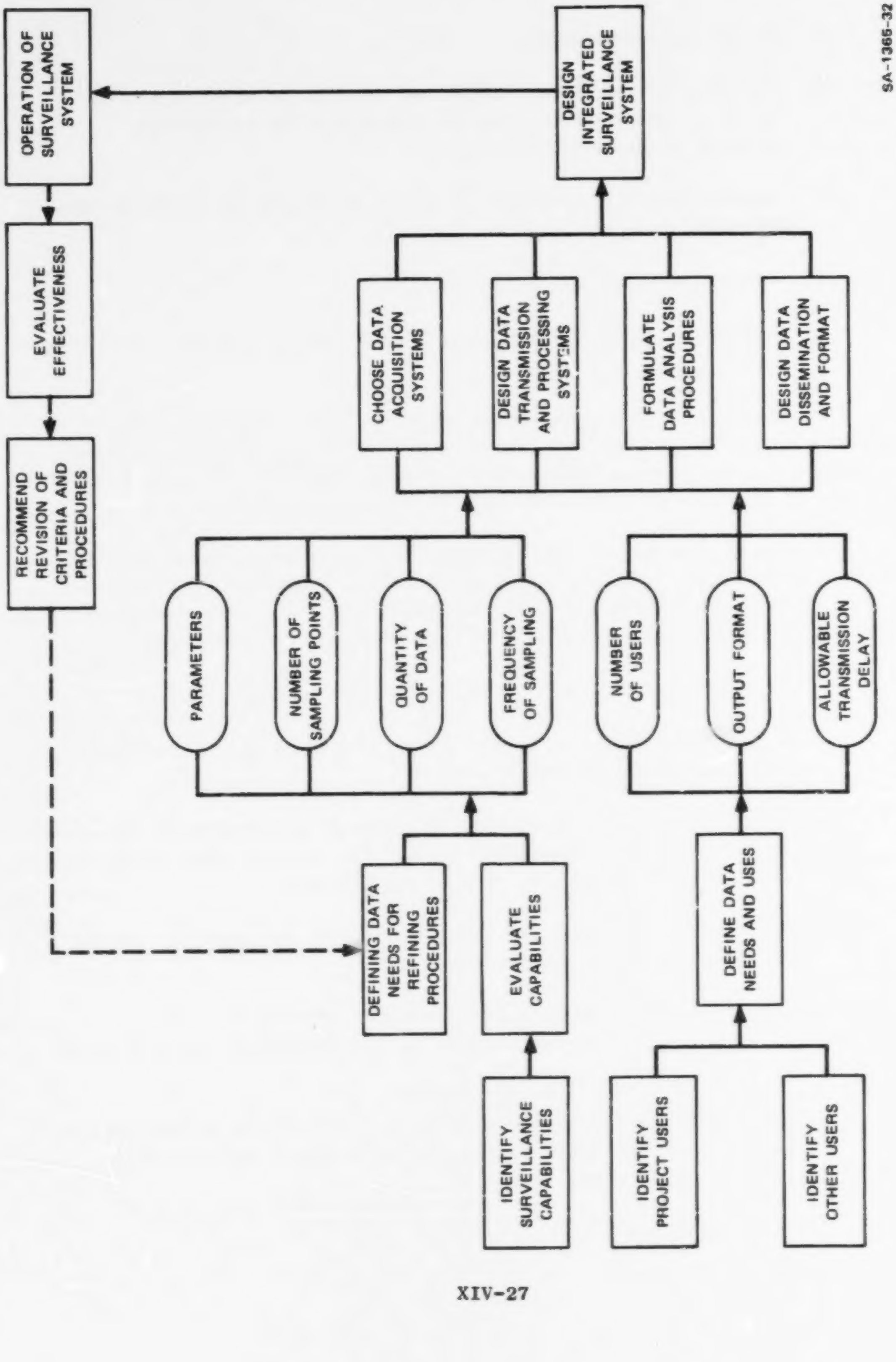
This is the subtask that encompasses the hardware aspects of the study. The approach will be to consider the following three aspects of hardware evaluation and selection:

(1) Identify the surveillance functions that can be fulfilled with ESD's present stock of instruments

(2) Review the candidate surveillance instrumentation, with a view to acquiring the specific hardware suitable for ESD's functions in the Regional Study

(3) Identify the more important surveillance applications.

Project personnel will probably perform these activities without field work or outside contacts other than liaison with EPA personnel in Las Vegas and other laboratories.


IDENTIFY SURVEILLANCE CAPABILITIES
EVALUATE CAPABILITIES
DEFINING DATA NEEDS FOR REFINING PROCEDURES
IDENTIFY PROJECT USERS
IDENTIFY OTHER USERS
DEFINE DATA NEEDS AND USES
PARAMETERS
NUMBER OF SAMPLING POINTS
QUANTITY OF DATA
FREQUENCY OF SAMPLING
NUMBER OF USERS
OUTPUT FORMAT
ALLOWABLE TRANSMISSION DELAY
CHOOSE DATA ACQUISITION SYSTEMS
DESIGN DATA TRANSMISSION AND PROCESSING SYSTEMS
FORMULATE DATA ANALYSIS PROCEDURES
DESIGN DATA DISSEMINATION AND FORMAT
DESIGN INTEGRATED SURVEILLANCE SYSTEM
OPERATION OF SURVEILLANCE SYSTEM
EVALUATE EFFECTIVENESS
RECOMMEND REVISION OF CRITERIA AND PROCEDURES

SA-1365-32

FIGURE XIV-3 AERIAL SURVEILLANCE SYSTEMS ANALYSIS CONCEPT

(1) Upper air meteorology

(2) Relation of individual pollutant sources to substandard air quality conditions in regions characterized by multiple sources or diffuse emission

(3) Surveillance of geographical areas difficult to reach by surface monitors

(4) Surveillance of mobile sources

(5) Impact of pollutants on agricultural lands, forests, and grass lands.

The emphasis is on measurements in which rapid response, mobility, and/or a synoptic view are key elements. These requirements also must be respected in designing subsystems for data recording and information processing and analysis, as discussed in subsequent sections.

The overall capability of the particular subsystem design for the aerial surveillance function will depend on the sensor/aircraft interaction as well as the sensor's characteristics per se. The subsystem capabilities may be divided into the following general categories:

(1) Capabilities defined by the particular sensor

(2) Capabilities defined by the sensor platform only (sensitivity of altitude and altitude control)

(3) Capabilities defined by both the sensor and platform (the ground resolution as determined by the angular resolution of the sensor and the altitude of the aircraft)

(4) Suitability for both day and night operation under a variety of meteorological conditions.

Preliminary discussions with ESD personnel have indicated the availability, now or in the near future, of the following types of hardware:

- Photographic equipment--70-millimeter forward and 5-inch vertical cameras, four Hasselbad multispectral cameras, and a 9-inch gyrostabilized camera

- Side-looking radar

- Infrared scanning system
- Accelerometer
- Nephelometer
- Vortex thermometer
- Black-body references for infrared system
- PRT-5 Barnes infrared thermometer (narrow view)
- Turbulence instrumentation
- Air quality instrumentation--ozone, sulfur dioxide, total hydrocarbon, and condensation nuclei instruments.

One of the turbojet aircraft is equipped with a radio altimeter and a Doppler guidance system. ESD is now in the process of incorporating the Doppler guidance system into an airborne wind measuring system. The group has also looked at the feasibility of acquiring inertial guidance systems to replace the Doppler systems, and they may proceed along these lines if sufficient needs develop. The current Doppler system, which is being implemented or incorporated into a wind measuring capability, has the ability to resolve aircraft drift angle to within 0.1 degree and wind speed to within ± 2 or 3 knots.

Based on work at the NCAR, it appears that the inertial system provides greater accuracy. The accuracy of the inertial system is limited only by the resolution with which the air speed of the aircraft can be measured; furthermore, this will be a function of the type of aircraft being used. The inertial system is capable of resolving the mean wind-speed components (u, v, w) to approximately one meter per second. Greater accuracy can be obtained but the one meter per second value is a conservative estimate. Wind-speed fluctuations can be obtained with a frequency of 100 per second and can be resolved to 10 cm per second. In comparison, the Doppler type system indicates that the mean winds can be resolved only to within a factor of two meters per second. If this is the case, it appears that the inertial system may be given a higher priority in spite of the larger initial cost.

It is estimated that an inertial guidance system alone (at commercial prices) will cost in the neighborhood of $100,000 to $150,000; the purchase and fabrication of the true air speed measuring equipment will cost approximately $25,000, while the recording system and miscellaneous sensors should cost in the neighborhood of an additional $10,000. The overall cost of the system, therefore, will be between $150,000 and $200,000. The Doppler system, on the other hand, would cost approximately $75,000 to $125,000 less than the inertial system.

Assuming the continued use of the acquired instrumentation for WERL's broader mission for EPA, these costs should be only partially allocated to the Regional Study. The details for funding WERL's activities within the Study will be negotiated by interagency agreement under the overall memorandum of understanding.

With respect to service facilities for the fixed-wing and rotary aircraft in the St. Louis area, WERL has an arrangement with the Air Force to utilize their facilities throughout the country. Therefore, they expect to be able to base their aircraft at Scott Air Force Base, Belleville, Illinois. WERL also expects to have available the C123 aircraft to be used both for transport and as an instrumentation platform, and the C-45 aircraft with a capability of carrying eight persons or a 1500-pound payload. Final selection of aircraft and instrumentation should be accomplished by the end of the first year of the Study.

Chapter XV

GENERAL CLIMATOLOGY OF ST. LOUIS

Introduction

Seasonal climate, and even the daily weather, of an area essentially is conditioned by the character of the prevailing air mass or the interaction of air masses over that region. An air mass can be defined as a large body of air (approximately 1000 miles or greater in horizontal extent) which takes on the particular temperature and humidity properties of the land or sea area (source region) over which it resides--the coldness of polar regions, the heat of the tropics, the moisture of oceans, and the dryness of continents. Because of the uniform distribution of temperature and humidity properties, the weather over an area associated with a given air mass tends to be quite similar, with local variations due to geographical features. The four basic types of air mass can be characterized as "cold moist," "cold dry," "warm moist," or "warm dry" depending on the geography of the source region (polar or tropical) and the underlying surface, maritime (water) or continental (land). Air masses over a given source region vary in their properties of temperature and moisture from season to season, as the properties of the source region undergo seasonal change.

These air masses are exported from their source region by the action of large pressure systems--cyclonic storms and anticyclones, and it is the interaction of these air masses that produces weather--fair or foul. The midlatitude of the United States is a favored locale for these interactions.

The area of eastern Missouri and southern Illinois, by virtue of its location, is subject to a variety of weather, as well as rapid changes in weather resulting from the intrusions and interplay of cold, rather dry air moving south from Canada and the Great Plains, as well as warm moist air moving northward from the Gulf of Mexico (see Figure XV-1).

St. Louis and environs, which is approximately 400-800 ft above MSL, is characterized by flat to gently rolling terrain and is free of large bodies of water; therefore, there are no major physiographic influences on these air masses. Solar change during the year is pronounced and does contribute to the seasonal climate through the amount of radiation received,

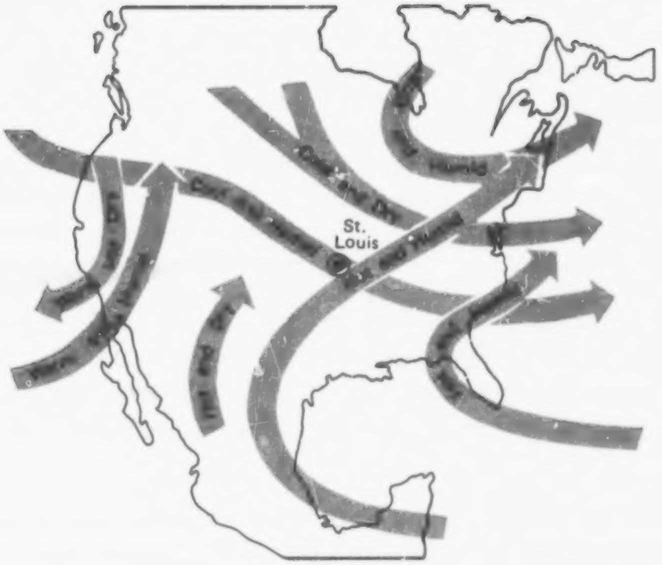


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FIGURE XV-1 TYPICAL PATHS OF AIR MASSES

e.g., the height of the noonday sun changes about 47° between solstices; the length of the shortest day (Dec. 22) is 9 hr 26 min, and the longest day (June 21) is 14 hr 53 min. Selected climatological characteristics are summarized by month in Table XV-1.

Principal Seasonal Meteorological Characteristics

Cold Season (Mid-October to Mid-April)

Between mid-October and mid-April, the area is subject to frequent changes in the prevailing air masses (Figure XV-2). Intrusions of cold air from the north (which may drop the temperature some 20° in a 24-hr period) are not uncommon but such cold spells are not long-lasting--generally much less than a week. By and large, winter is characterized by mild temperatures (seasonal average maximum temperature) with occasional short spells of extreme cold. The rapidity of the weather changes is due to the rapid movement of the cyclones. The warm inflow from the south in front of a depression is of almost as pronounced a character as the cold wave which suddenly takes its place when the trough of the depression has passed. Cold waves are coldest in the north of the United States. In the mid-course of the Mississippi the changes are especially noteworthy since the temperature often drops suddenly from well above, to well below, freezing-point, and such a change entails the maximum of inconvenience and discomfort. St. Louis has recorded 74°F and -22°F in January, that is to say, 42° above, and 54° below, freezing-point.

Some indication of the severity of the winter is given by the fact that about 70% of the January nights have a minimum of 32°F or lower and about 25% of the January days are continuously below freezing; somewhat smaller percentages prevail in December and February. Rapid warming takes place by March. The average date of the first 32°F temperature observed is about mid-October, the last 32°F temperature is observed about the beginning of April. Between October and April periods of warm temperatures extending into the high 80s are observed but the incidence is small.

Precipitation can be expected during all months in the period, largely in association with the passage of cyclonic storms or fronts. Generally, such storms move in a southwest to northeast path over the area and primarily during the winter and spring months. Such passages will bring precipitation in the form of rain, although periods of snow, sleet, or freezing rain are not uncommon. Post-storm conditions typically show fair skies with moderate to brisk surface winds. Typical tracks of low and high pressure areas are shown in Figure XV-3.

Table XV-1

SELECTED CLIMATOLOGICAL CHARACTERISTICS OF ST. LOUIS

STA NO. 72434 (IN AREA NUMBER 13) LATITUDE 3844N LONGITUDE 09021W ELEVATION(FT) 00571

PARAMETER DESCRIPTION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN	POR (YRS)	NO. OBS
ABS MAX TMP (F)	77	78	86	91	98	105	115	104	104	94	86	76	115	23	-113
MEAN MAX TMP (F)	40	44	53	66	75	85	89	87	81	70	54	43	66	30	-116
MEAN MIN TMP (F)	24	25	32	44	53	65	67	66	58	47	35	27	45	30	-116
ABS MIN TMP (F)	-14	-7	-5	24	33	47	52	50	32	22	3	-4	-14	23	-113
MEAN NO DYS TMP = OR GTR 90 (F)	0.0	0.0	0.0	0.3	2.0	11.0	16.0	16.0	7.0	0.3	0.0	0.0	52.6	10	-113
MEAN NO DYS TMP = OR LES 32 (F)	26.0	19.0	17.0	2.0	0.0	0.0	0.0	0.0	0.0	1.0	13.0	22.0	100.0	10	-113
MEAN NO DYS TMP = OR LES 0 (F)				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			23	-29
MEAN DEW PT TMP (F)	21	23	30	39	49	60	65	64	58	44	34	26	43	22	-29
MEAN RFL HUM (PCT)	68	66	64	60	63	66	68	68	71	63	69	72	67	6	-116
MEAN PRESS ALT (FT)	386	392	470	501	529	537	513	508	459	431	421	392	462	0	-50
MEAN PRECIP (IN)	1.98	2.04	3.08	3.71	3.73	4.29	3.30	3.02	2.76	2.86	2.57	1.97	35.3	30	-116
MEAN SNOW FALL (IN)	4.4	4.1	4.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	1.2	2.9	17.5	30	-116
MEAN NO DYS PRCP = OR GTR 0.1 IN	4.6	4.7	6.2	6.6	6.7	7.1	6.0	5.6	4.7	4.8	4.4	4.6	66.0	30	-29
MEAN NO DYS SNFL = OR GTR 1.5 IN	1.0	0.9	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	3.9	30	-29
MEAN NO DYS W/OCUR VSBY LES 1/2 MI															
MEAN NO DYS TSTMS	1.0	1.0	3.0	5.0	7.0	9.0	7.0	7.0	5.0	3.0	1.0	0.0	49.0	59	-24

Source: U.S. Naval Weather Service World-Wide Airfield Summaries, Volume VIII, Part 5, United States of America (Mississippi Valley Area), December 1969.

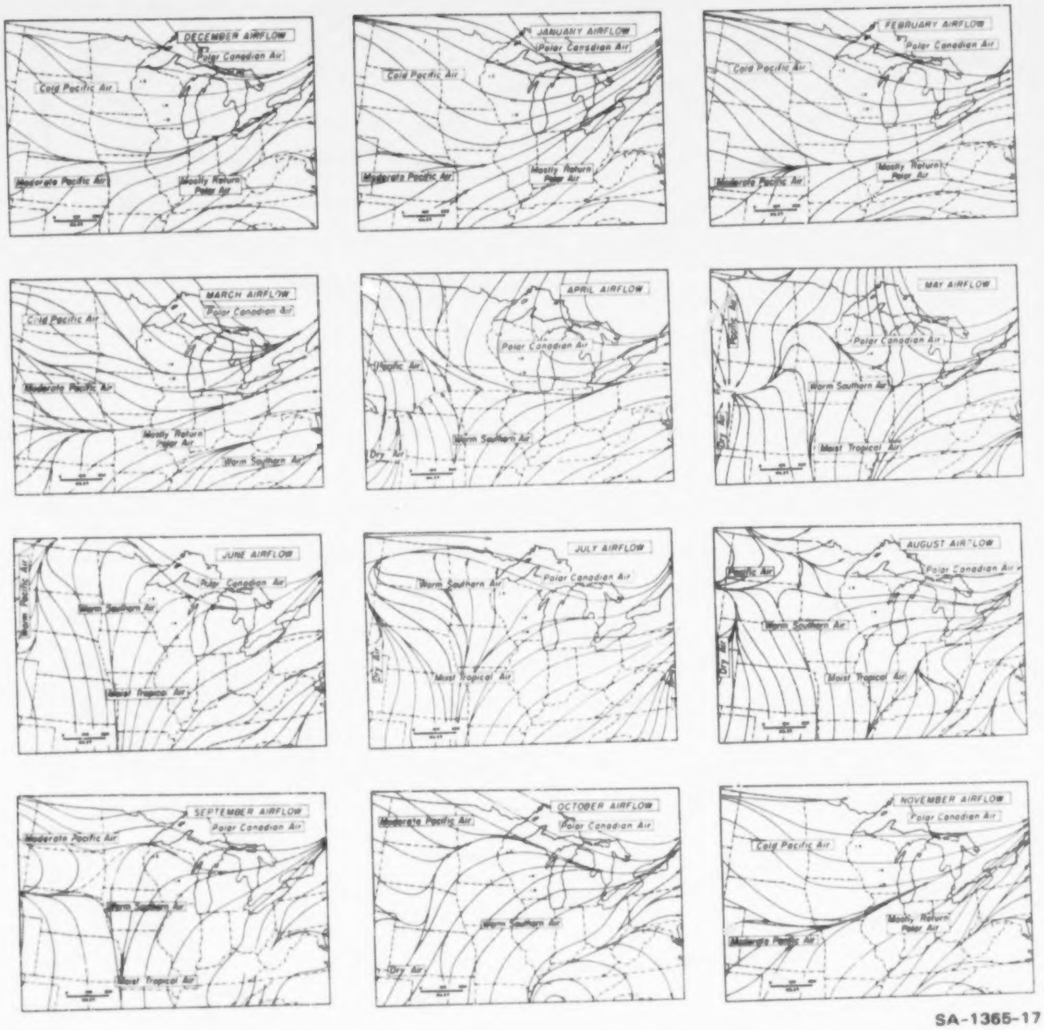

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FIGURE XV-2 MONTHLY DISTRIBUTION OF PREVAILING FLOW PATTERNS CENTRAL U.S.

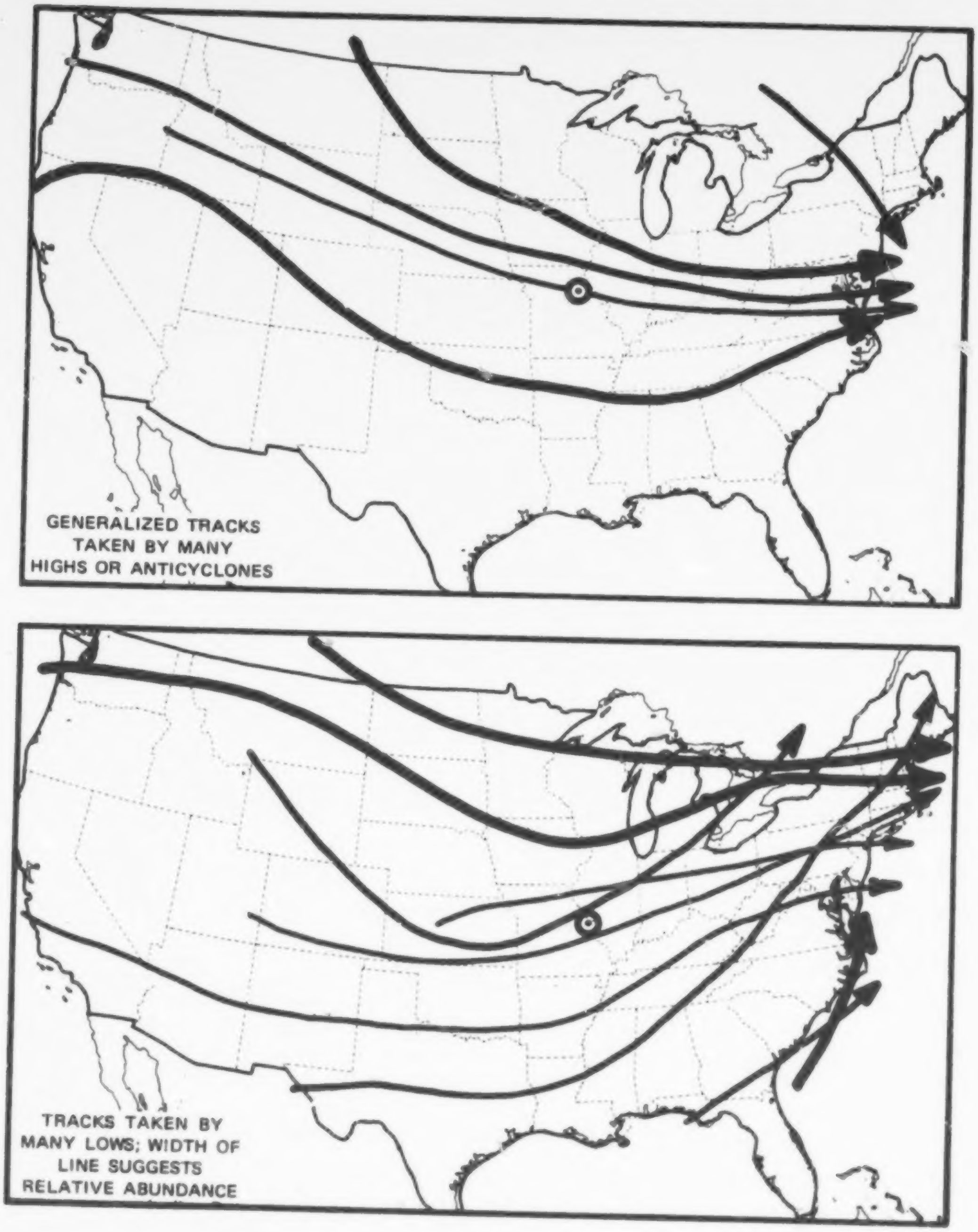

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FIGURE XV-3 GENERALIZED TRACKS OF HIGHS AND LOWS

The prepassage of the lows is often accompanied by extensive cloudiness so that the weather experienced at St. Louis will be common to its environs as well. Rainfall amounts vary from a little over 2 inches in December to slightly over 3 inches in March. However, in any given year the precipitation may vary as much as 1.2 to 1.5 times the seasonal long-term average. Snowfall amounts range from 3 inches in December to a maximum of 4.5 inches in February. Continuous precipitation episodes rarely last longer than 1 day. Copious precipitation does occur on occasion, for example, precipitation ≤0.01 inch occurs on an average of 8-11 days a month in this season; precipitation ≤0.50 inch on 1 to 2 days per month. The normal annual daily rainfall probability is about 25%. Thunderstorms are recorded on an average of 1 day per month December through February, 3 days during March and about 8 days in April, concomitant with the onset of spring.

The mean sky cover in this season remains virtually the same in all months (approximately 6/10 coverage), the average percentage of possible sunshine varies from 44% in December to 59% in April. The average relative humidity during this season varies from 70-75%; however, the average relative humidity between 1 AM and 7 AM is 77%; between 1 PM and 7 PM it is about 66%. Fog is observed in all the cold months with maximum occurrence December through February.

The prevailing (most often observed) surface winds are from a northwesterly direction in winter and early spring. The typical storm tracks (Figure XV-3) are such that a bi-model frequency of directions (from the south and from the northwest) appears in the wind roses from October through April. Wind speeds are generally less than 10 mph on the average, with most of the wind speed ranging from 4-18 mph. Strong winds (in excess of 30 mph) occur infrequently (less than 15% of the observations), but speeds reaching nearly 60 mph have been recorded in the months December through February and a peak value of 82 mph in April. All the high speeds were observed for winds from a southwesterly direction.

Figure XV-3 indicates that the central United States is a preferred region for anticyclonic tracks. This, in turn, generated a rather high incidence of stable thermal conditions over this area--primarily during the night and early morning hours, concomitant with clear skies and light winds. Inversions are reported on about 35% of the total reported observation hours in winter and 28% of the total hours in early spring.

Except for short periods, the weather in this season does not restrict airport activities. Airport observations indicate a ceiling above 1000 ft on about 85% of the observations; visibility is above one mile about 85% of the time. Taken in combination, a ceiling of less than 300 ft and/or a visibility of less than one mile occurs less than 6% of the time.

Warm Season (Mid-April to Mid-November)

Beginning in late April and extending through about mid-October, the area is dominated by warm and moisture-laden air from the Gulf of Mexico (see Figure XV-2). Summers remain consistently warm (average daytime temperatures in the 80s) with short spells of hot weather, having temperatures over 100°F. The cold waves of winter have a summer parallel in the hot waves of the south and east of the United States, which are spells of hot weather with very moist air, brought by the south and south-east winds which blow when an anticyclone is situated off the east coast, and a low-pressure system lies over the Mississippi valley. The moist heat is very enervating though the thermometer may not rise above 100°. It even causes many cases of heat stroke and prostration. Considerable cooling takes place at night; however, minimum temperatures of less than 32°F are not observed from May to September. Maximum temperatures in the high 90s begin to occur in May and readings exceeding 100°F are observed in all summer months and into September. Marked cooling takes place through October. The average monthly temperatures between June and September fall within the range 70-80°F, the average diurnal range is about 22°.

The onset of spring brings with it spells of thunderstorms and humid conditions. In fact, during late spring, summer, and early fall, most of the precipitation is the result of thunderstorm activity. Such rainfall is usually of short duration, but may be of heavy intensity. Monthly precipitation amounts average between 3 and 4 inches. An occurrence of 5 thunderstorms in April, increasing to 10 days in June, and receding to 5 days in September has been recorded in the long-time averages. Put another way, the normal number of thunderstorms is 17 in spring, 27 in summer, and 9 in fall. In summer about 40% of the thunderstorms occur between noon and 6 PM; about 24% occur between 6 PM and midnight. As in winter, the range of precipitation for a given year can vary as much as 1.5 times normal precipitation value. Hail is common in April and May, averaging nearly 1 occurrence per month. Tornadoes are not uncommon and can be expected during the months from May through September, in particular. About 7 are reported annually and May normally has the greatest frequency. The mean relative humidity in the period April to October varies between 65 and 72%; the diurnal range is marked, averaging 74% between 1 AM and 7 AM and decreasing to 50-58% in afternoon hours 1 PM to 7 PM.

Summer is characterized by rather fair skies. The average sky cover varies from an average of 6/10 in April to a minimum of slightly over 4/10 from July through October. Sunshine is recorded for 60% (April) to 72% (July) of the available sunshine hours. Light to moderate fog is reported rather infrequently in summer and dense fog hardly at all.

Surface winds during the period May through October are primarily from the south, at a mean speed of 7 to 8 mph. Occasional strong winds occur, however, usually from southwesterly directions, and have been reported as strong as 60 mph in April through August, with a maximum of 73 mph being recorded in September. Speeds generally reach a maximum during the afternoon.

In summer there is a definite tendency for nocturnal stability and daytime instability in the lower levels; inversions are reported on 28-35% of the total hours during spring and summer and increasing to 43% in the fall months. Of these occurrences, some 60-80% are reported at 9 PM and 7-15% at 9 AM, illustrating the effect of nighttime cooling and generally fair skies. Flying weather during this period is good. Ceilings greater than 1000 ft and/or visibility greater than 1 mile are reported in excess of 97% of the observations. Short periods of reduced ceilings and visibilities will occur with the presence of thunderstorm activity.

Meteorological Parameters Relating to Pollution

The meteorological parameters that, perhaps, contribute most to incidents of air pollution are stability and wind speed. Therefore, the climatology which delineated the simultaneous occurrence of these episodes--and other parameters in which these factors are involved--is of special interest.

Stagnating Anticyclones

Over the Great Plains anticyclones generally are characterized by strong stability (inversions) in the lower levels, clear skies (which, through radiation loss, contribute to stability) and sluggish surface circulation, particularly if the anticyclones remain over an area for an appreciable amount of time. A study by Korshovev[1] places this period at 4 days or more. His data indicate that the St. Louis area experienced nine cases of stagnation lasting four days or more (for a total of 42 stagnation days) in a 30-year period; there were two cases where the stagnation lasted seven days or more. Seasonally, the frequency shows a minimum in winter and a maximum from April to June, followed by a sharp decrease in July and a continuous increase to an absolute maximum in the month of October. Hosler[2] has also pointed out that, while "precise frequency values of low-level inversions may not be obtained for a specific location from wind speed and cloud cover data alone, isopleths of percent frequencies of cloud cover and wind speed indicate that the general areas having a higher frequency of inversions are also characterized by a higher frequency of relatively clear nights with light winds and vice-versa." His data show that the percent frequency of nighttime cloud cover of 3/10 or less is about 36% in winter, 44% in spring, 55% in summer, and 60% in the fall. Likewise the percent frequency of nighttime wind speed 7 mph or less is at a minimum (20%) in winter; 40% in spring; 65% in summer and fall. Taken together, the occurrences of nighttime cloud cover ≤3/10 and wind speed ≤7 mph follow the same trend; a minimum of 31% in winter, 42% in spring, 62% in summer, and 60% in autumn. Specific data on inversion frequency at St. Louis are given in Table XV-2. Hosler

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[1] Julius Korshovev, "Climatology of Stagnating Anticyclones East of the Rocky Mountains, 1936-1965," National Center for Air Pollution Control, Cincinnati, Ohio (1967).

Table XV-2

FREQUENCY OCCURRENCE OF TOTAL HOURS OF INVERSIONS

	Winter	Spring	Summer	Fall
Percent of Total Hours	35	28	35	43
Percent frequency (maximum observed)	61	60	81	83
Percent cloud cover ≤3/10, percent wind speed ≤7 mph	30	40	58	60
Percent frequency at GMT				
03(9PM LST)	63	60	82	81
15(9AM LST)	24	11	7	13

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2. Charles Hosler, "Low Level Inversion in the Contiguous United States," Monthly Weather Review, 319-339, September 1961.

also remarks that

> "the higher frequency during fall and winter probably is a reflection of minimum storminess in fall and maximum length of a stable nocturnal period in winter. The opposite is true for the spring and summer months. During the colder months, particularly if snow cover exists, warm southerly advection over an existing cold surface may enhance low-level stability in these areas; however, such advection regimes are usually the incipient stages of warm fronts and cyclones with their associated precipitation and storminess, which ultimately produce less stable lapse rates below 500-foot elevations above ground."

A parameter that expresses the potential for vertical mixing of the air is the "mean maximum mixing depths." It is apparent from Hosler's data that at night the mean extent of vertical mixing over the Great Plains generally is small (less than 1000 ft). Holzworth[3] indicates that where these depths are shallow (less than 3000 ft and preferably less than 1000 ft) the likelihood of extended periods of limited vertical mixing is large; where they are deep (greater than 3000 ft) such likelihood is small. The mean maximum mixing depths over the Great Plains vary greatly by season (see Figure XV-4). The computed values for the St. Louis area average about 1200-1500 ft for winter; 3000 ft in spring; 3000-4000 ft in summer and early fall followed by a marked reduction to 2000-2500 ft in October and November.

In another study Holzworth[4] presents the mean annual morning and afternoon mixing heights. He defines the "mixing layer" as "the surface-bounded layer of the atmosphere through which relatively vigorous vertical mixing occurs." Solar heating results in mixing layers that are common over mid-latitude regions during the day. Such mixing layers are also present over cities at night and Holzworth suggests that "it is not uncommon for mixing heights over urban areas to vary diurnally by more than two orders of magnitude. Over rural areas the nighttime loss of height results in inversions in which vertical mixing is minimal."

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[3] George C. Holzworth, "Estimates of Mean Maximum Mixing Depths in the Contiguous United States," Monthly Weather Review, 92, No. 5, 235-242, May 1964.

[4] George C. Holzworth, "Meteorological Potential for Urban Air Pollution In the Contiguous United States," paper No. ME-20C presented at the Second International Clean Air Congress, Wash. D.C., Dec. 6-11, 1970.

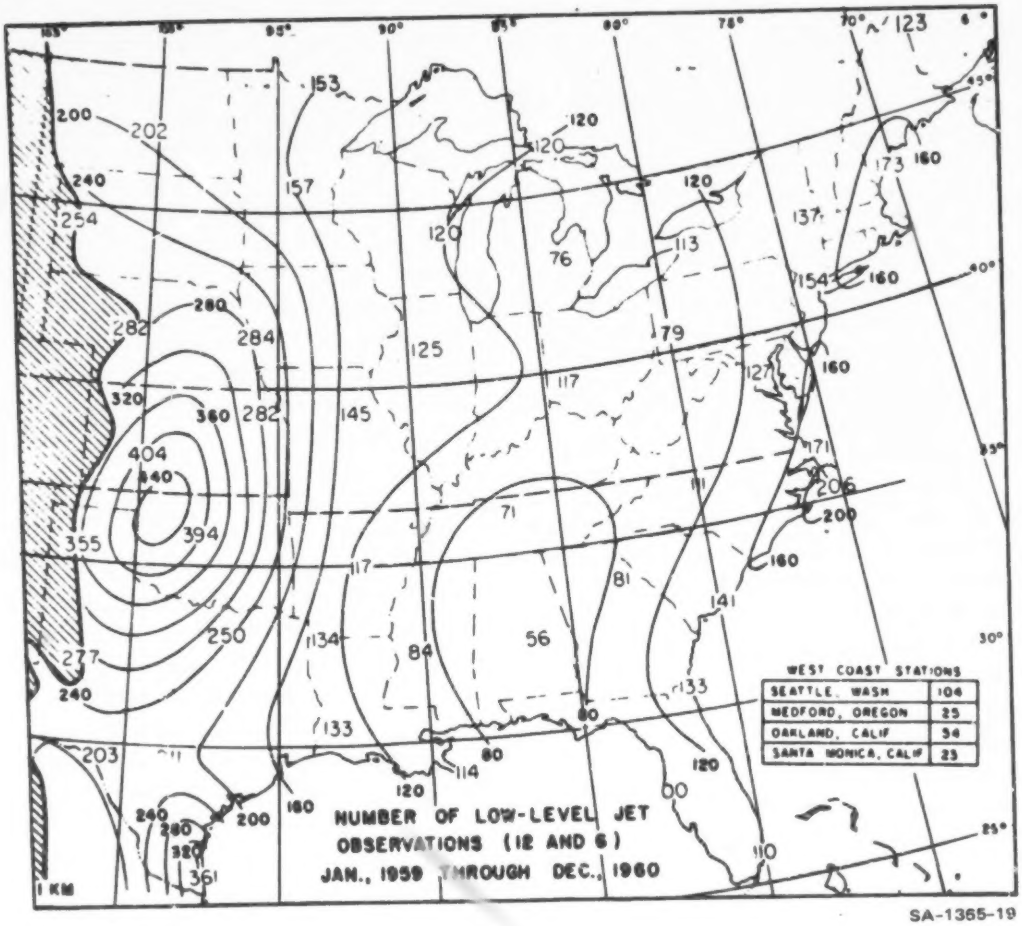

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FIGURE XV-4 GEOGRAPHIC DISTRIBUTION OF A NUMBER OF LOW-LEVEL JET OCCURRENCES FOR A TOTAL PERIOD OF TWO YEARS, ACCORDING TO EVALUATIONS BY BONNER (1965) OF UNITED STATES WEATHER BUREAU SYNOPTIC PILOT-BALLOON NETWORK DATA

In the St. Louis area, the mean annual morning mixing height is about 1200 ft; the mean annual afternoon mixing height is about 4500 ft. Holzworth states that the morning mixing heights, for the most part, do not vary greatly on a seasonal basis; they are roughly 350-700 ft higher than the annual mean in spring and about 350 ft lower than the annual mean in summer and autumn. Afternoon mixing heights display considerable differences in their seasonal upper limits, ranging from a value of 5000 ft in winter to values above 10,000 ft in summer.

Wind

Dispersion of pollutants, of course, is also dependent on wind speed. The mean annual wind speed averaged through the morning mixing layer for the St. Louis area is about 5 m/sec^{-1} and about 6-7 m/sec^{-1} averaged through the afternoon mixing layer. The predominant direction for light winds is from the southeast. In general, the faster speeds occur in spring. Maximum seasonal afternoon speeds (averaged through the layer) is 10 m/sec^{-1} and minimum seasonal morning speeds are less than 2 m/sec $^{-1}$.

Holzworth also presents data on episodes of limited dispersion* which indicate that stated criteria in eastern Missouri and western Illinois occurred a total of approximately 30 episode-days in a five-year period; the autumn season contained most of the total occurrences.

A parameter of importance to pollution considerations is the so-called "low-level jet stream." It is generally a summertime phenomenon, occurring during the nighttime hours. Characteristically, the wind field in the lower 1500 ft above the surface begins to increase in speed from a southerly quarter, and to decrease in speed above the 3500 ft level. The speed increases to a maximum of about 45 knots at about 1500 ft shortly after midnight after which unstable lapse-rates prevail. Data presented by Bonner (see Figure XV-4) show about 125 observations (12 and 6) of the low-level jet in the St. Louis area during a two-year period. Also, it has been shown by Bonner that the nocturnal thunderstorms, not associated with frontal activity, are significantly correlated (in time and space) with the presence of a low-level jet stream.

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* Defined as follows: (1) all mixing heights 5000 ft or less, (2) all mixing layer average wind speeds 4 m/sec^{-1} or less, (3) no significant occurrence of precipitation during 12-hr periods covering each mixing height calculation, and (4) above conditions satisfied continuously for at least 2 days.

Chapter XVI

LAND AND BUILDING REQUIREMENTS

The Regional Study requirements for land and building space have two principal components. The first covers the central facility itself, and the second includes land for the instrument stations. The general characteristics and selection criteria for building space and instrument station sites are provided in the following discussion.

Central Facility

Selection Criteria

The building space requirements for the St. Louis central facility consist of two types. The first covers administrative and other office space necessary for the bulk of the permanent staff, temporary research personnel, and the data-processing equipment. The second includes space necessary for instrument repair and outfitting of the transportable instrument stations, the chemical laboratory, and related functions. Ideally, these two functions would be located within the same structure but a modest separation ought not hamper efficient operations. Since the metropolitan St. Louis area has many types of structures potentially available, satisfactory space in existing structures should be readily acquired. The precise location will, of course, depend upon availability, rent or lease terms, and similar local factors. Several basic technical factors should be considered in location selection.

First, since marked utilization of aircraft is anticipated in many of the research experiments as well as for routine data gathering, serious consideration should be given to locating the central facility near an airport. The airport need be of only modest size but should have maintenance and fueling facilities and should be in continuous 24 hour operation. Facility location near an airport would clearly facilitate the transfer of airborne-acquired data to the computer facility for logging. Additionally, air sample containers could be quickly transported to the laboratory facilities for expedient analysis. Finally, in the event that helicopters are included in the system, personnel and equipment may well be transported to the more remote rural sites far more efficiently and quickly than by surface transportation.

A total of 16 commercial airports are situated within about 30 miles of the central St. Louis area. Twelve of these, however, are judged to be inappropriately located for purposes of the Regional Study because they are generally located south and west of the central area. Lambert Field is included in the twelve, and it could be eliminated because of expected operational constraints, and one--Lakeside Airport east of Granite City, Illinois--tends to be too small and lacks facilities. Since the bulk of the airborne and surface monitoring will likely be carried out in the northerly and easterly directions from the central area, the airport location should lie in the same general area. The remaining three possible sites include: the Bi-States Park Airport at Centreville, Illinois; Civic Memorial Airport at Bethalto, Illinois; and Collinsville Airport at Collinsville, Illinois. In addition to these three commercial airports, Scott Air Force Base should be included as a significant candidate. The most centrally located airport is perhaps the Civic Memorial Airport near Bethalto.

Second, the facility should be situated roughly at the center of the instrumented area. This location may tend to minimize data transmission costs and reduce the difficulties of moving personnel and equipment between the central facility and the instrument sites. Since the instrumented area may be somewhat biased to the north and east of St. Louis, the central facility should be similarly displaced.

Third, the location should be sufficiently near the St. Louis central area to permit expedient negotiations with local equipment vendors and suppliers, especially during the conduct of a research experiment when unforeseen requirements may arise for additional equipment, laboratory chemicals, or similar reasons.

Fourth, the central facility is intended to serve as the site for a prototype instrument station and as a test bed for subsequently developed meteorological and air quality instruments prior to their incorporation in the instrument system. Consequently, the site should incorporate an open unobstructed area of at least one-fourth an acre. Moreover, because of the possible interference of the facility building with wind flow conditions, the instrument station site should be slightly removed from the facility building site itself. Thus, housing of the facility in a multi-floored structure should be avoided if at all possible. Any appreciable separation of the instrument site from the laboratory and shop facilities will obviously create difficulties in day-to-day operation. Zoning regulations at the site naturally must be such that a 30-meter tower can be erected. This factor may control the proximity of the facility and tower site to the airport.

Finally, the facility should be located near one or more of the principal freeway routes in the St. Louis area to reduce travel times to the instrument sites.

On the basis of these criteria, the most appropriate general location in regard to commercial airports appears to be in the Alton-East Alton vicinity near the Civic Memorial Airport at Bethalto. The location tends to be to the north and near the center of the instrumented area and is well served by the freeway system. The Civic Memorial Airport is perhaps the most fully developed airport in the area, short of Lambert Field, so that all appropriate services should be available. The Alton-East Alton area is sufficiently close to St. Louis itself to facilitate procurement of equipment, supplies, and spare parts without undue delay and difficulty.

Scott Air Force Base stands as a strong alternative to the commercial airport. Appropriate facilities should exist for aircraft maintenance, fueling, and other tasks. The base likely will have existing buildings which can be utilized for office and data-processing use as well as suitable shop areas. The base tends to be slightly isolated in terms of the freeway network and is also somewhat further than East Alton from the comparatively dense instrument system in the urbanized area of St. Louis.

Some difficulty is likely to be encountered with the day-to-day problems of housing, transport, and the like, of the temporarily located research experimental groups. Entry and exit of such groups is likely to be at Lambert Field in St. Louis, about 35-40 surface miles from Scott Air Force Base. Public accommodations may on occasion be difficult to find with the nearest large community being Belleville, Illinois, about seven miles to the west. Perhaps accommodations could be located on the base itself, but this may involve difficult administrative procedures, especially if contractor personnel are involved in the research experiments. All these drawbacks notwithstanding, Scott Air Force Base deserves serious consideration, especially since EPA is currently authorized to use the base for aircraft operations.

An additional set of factors should also be considered for the location of the central facility. First, undoubtedly requirements will develop for coordination and liaison with local, state, and federal agencies in the St. Louis area, who have responsibilities and interests in air quality and meteorology. Most of these groups are likely to be situated in the urbanized St. Louis area at some distance from the airport sites, so that efficient coordination might be difficult.

Second, public support of the Regional Study would clearly be of considerable value. The development of the emission inventory, for example, could likely be facilitated by such support, and, perhaps, the difficulties of acquiring the instrument station sites could be markedly lessened. The location of the central facility at a site near or even within the urbanized St. Louis area could well enhance the general visibility of the Regional Study and aid in the development and maintenance of public support. Such benefits, of course, should also flow to other air quality and meteorological studies in the St. Louis area. The extent to which the central facility might feature special exhibits and displays to develop awareness and understanding of the Regional Study is difficult to assess at this time but might well be considered in subsequent planning.

Thus, final selection of the central facility site should merge the strictly technical factors favoring an airport location with those suggesting a more urbanized location. If, on balance, the technical considerations predominate, then either the Alton-East Alton or Scott Air Force Base areas should be given the highest priority in site selection. On the other hand, if the need for coordination, high visibility, and related factors outrank technical considerations, then sites in central and northern St. Louis should be favored for selection.

Interior Space Requirements

The estimated requirements for space at the central facility are presented in Table XVI-1. The general office and data-processing areas have the normal requirements for heating, lighting, acoustics, and related factors. Additionally, the area must be suited to necessary modification to accommodate the special requirements of the data-processing equipment, including any cooling equipment and ducting, cabling, and the like. Space allocation is primarily based upon the number of staff members estimated for the facility, as discussed in Chapter XIX with an allocation approximating 150 square feet per office. An additional 400 square feet has been established for use by the temporary experimental research groups when working in the facility. A total of 500 square feet has been allocated for the data-processing center which should be sufficient for all equipment as well as storage space for tapes, cards, and other materials. This area should also be adequate to provide for maintenance and work space around the equipment. The total office/computer space is estimated at approximately 3,900 square feet. This includes a contingency allowance of 775 square feet for hallways, waiting rooms, and the like.

The requirements for shop and laboratory space total 1,800 square feet. The experimental research program requires a well equipped chemical laboratory. Appropriately, it should be a "wet" laboratory with all basic laboratory utilities--municipal and deionized water, electric power, gas, air, and the like. Additionally, it would be provided with standard

Table XVI-1

INTERIOR SPACE REQUIREMENTS FOR THE CENTRAL FACILITY

	Square Feet
Office/computer space	
System chief	200
Research program coordinator and staff	300
Meteorologist	150
Instrument system engineers	350
Data processing	500
Chemical engineer and field staff	250
Clerical, files, office supplies	400
Conference room	200
Library, engineering files	200
Effects research	150
Experimental research group	400
Subtotal	3100
Hallways, waiting room, and miscellaneous @ 25%	775
Total	3875
Shop/laboratory space	
GC mass spectrometer laboratory	400
Chemistry laboratory	400
Humidity controlled storage	100
Instrument installation	500
Electronic service	100
Other service	100
Parts storage	200
Total	1800
Grand total	5675 (~5700)

laboratory reagents, glassware, and laboratory bench facilities with sufficient space for specialized equipment provided on a temporary basis for the experimental research groups.

Bench space will be required for instrument calibration, maintenance and modification, and similar tasks. These tasks can be divided into electronic and mechanical activities, and they should be provided with separate work areas. The former would be fitted with the necessary diagnostic electronic instrumentation and related equipment. Mechanical activities would require facilities to accommodate a variety of tasks, including glass blowing for special instrument repair and fabrication, metal cutting and forming, and similar functions which will clearly arise during the course of the Regional Study.

An appreciable area will also be required for servicing and modifying the transportable instrument stations of the facility. The space should be sufficiently large to house at least one of the mobile calibration vehicles, so that access from the outside can be gained by means of large garage-type doors; interior ceiling heights should be in the range of 10-12 feet. The servicing of the transportable instrument stations will consist primarily of the installation and change of air quality instruments as dictated by the experimental research program. Minor modifications of the instruments likely can be carried out in the field as part of the routine maintenance program. However, at the conclusion of major research experiments when significant equipment changes would be in order and probably most appropriately carried out during the winter months of minimal field activity, the service space will be in continuous use. The space requirements, accordingly, are based upon housing two transportable instrument stations at one time for simultaneous servicing. These stations are estimated to be approximately 90 to 120 square feet in area. The simultaneous housing of two transportable stations and one mobile calibration vehicle is estimated to require 500 square feet including service and working space about each unit.

Outdoor Facilities

The outdoor facilities are expected to consist mainly of parking and storage space. Space, of course, will be required for the prototype instrument station and tower. A guyed 30-meter tower, for example, requires approximately one-fourth acre and should be near electric power and telephone facilities. All prototype station test activities likely can be carried out within this area with no problem.

Adequate parking facilities will be required for the permanent staff, experimental research personnel, vendor representatives, and others.

Approximately 40 spaces should be provided for an aggregate area, including movement space, of approximately one-half acre or 20,000 square feet.

A securely fenced outdoor equipment storage area is required for the calibration trailers, Class C instrument stations, and miscellaneous general equipment. Storage space of the order of 10,000 square feet should be adequate. However, on occasion additional temporary space may be required.

Instrument Station Sites

Selection Criteria

The instrument sites associated with the Regional Study should generally be selected with respect to at least eight criteria; these are:

- Freedom from unique or overriding micrometeorological effects caused by structures, vegetation, and topography
- Minimal deviation from analytically defined location
- Absence of nearby significant pollutant sources
- Convenient availability of electric power and communication utility services
- Area stability with respect to land usage, emission sources, and the like
- Free access at all times
- Minimal zoning restrictions and institutional constraints
- Suitable site size.

The requirement for absence of unique micrometeorological effects is perhaps one of the most important. Since the measurements taken at each site will be used as the basis to define the meteorological and pollutant conditions or fields throughout the entire region, the measurements should represent insofar as possible the free field conditions in the area of each station. Small-scale anomalous conditions can indeed seriously impair the value of the data acquired. Difficult compromises in the urbanized area may be required, because available sites may be limited.

The need to achieve the least deviation from the analytically defined station location clearly is of importance. Minor adjustments to conform with other criteria should be permissible but large displacements could necessitate review and adjustment of numerous other stations as well.

The criterion of absence of nearby significant pollutant sources will vary with the type of instrument station. The stations intended to monitor the ambient air quality must generally meet this criterion. On the other hand, the more specialized Class C transportable stations sited for certain unique research experiments may indeed appropriately ignore this criterion.

The nearby availability of electric power and communication utility services will be required at the Class A and B stations, and at least electric power would be desirable at the Class C stations. At a cost, both services can be made available at any point in the Regional Study area. Clearly, however, in the absence of compelling reasons, especially lengthy power and communication drops should be avoided in favor of adjustment of location. Lengthy drops increase both the costs and expected outage times and should be avoided. The Class C stations are designed to be equipped with engine-generator sets in the event that electric power is not available. Although these are suitable power sources, their use tends to increase servicing and maintenance times and their exhaust and noise levels may introduce site location problems. On the other hand, Class C stations for certain research experiments may be emplaced for periods as short as two to four weeks, in which case the installation of commercial power drops may not be justified because of their cost. As noted in the discussion of digital data links, a number of the telephone utilities in the Regional Study area have plant facilities not altogether suitable for data transmission and are not firmly interconnected with the larger utilities in the area. Accordingly, these factors should be balanced--in terms of locating the site within the larger integrated telephone utility service area with perhaps lengthy drop distances--against the special engineering design and modification required of the smaller utility if it is to achieve the proper transmission and switching characteristics.

The criterion of area stability covers the general pattern of land usage in the vicinity of the instrument site. The essential aim is to select instrument sites in neighborhoods which appear to offer the smallest possible change in land usage over the course of the Regional Study. For example, a well-developed residential area with moderately new structures or city parks would tend to remain much the same over a five-year period except, perhaps, for the growth of vegetation. Areas to be particularly avoided would be rapidly developing suburban residential and commercial areas and areas of the central city planned for large urban renewal projects. The purpose of this criterion is simply to ensure that changes in the instrument station measurements over time be caused by meteorological variations and emission levels rather than local changes in land usage causing micrometeorological anomalies or the establishment of a new pollutant source near the instrument station.

The need for free access to the site at all times is, of course, of extreme importance. With proper arrangements, this criterion should present little if any difficulty but nevertheless should not be overlooked. The rural stations should be selected so that winter weather conditions do not hamper or prohibit access.

The criterion pertaining to zoning restrictions and institutional constraints will likely vary somewhat directly with the degree of urbanization. The constraint of particular importance is any limitation on structure height and the manner in which instrument towers are interpreted within such limitations. Other constraints of importance include exterior structural design and its possible impact on instrument shelter design, site security fencing, materials storage including chemicals and high pressure cylinders, and related factors.

Site size will vary with the class of station and the tower selected for use. Sites having 30-meter guyed towers will require a square one-fourth acre plot in order to enclose the guy anchors. Sites of this size may be difficult to acquire in the urbanized area, in which case an unguyed self-supporting tower will be necessary. In this event the site may be reduced to approximately 50 x 50 feet. The Class B instrument stations without towers also require a square 2500 square-foot site.

The Class C stations with the smaller instrument trailers require approximately 200 square feet (10 x 20 feet). Formal negotiation and acquisition of these sties is not anticipated. Since the Class C stations will be emplaced for relatively brief periods, somewhat less formal authorization procedures for site usage with property owners should be possible.

Implementation

The process of actual site selection and acquisition will consist of six principal tasks. First, analytically derived pattern of station location, as provided in this Prospectus, should be comprehensively reviewed and reassessed in the light of the actual allocation of funds for the Regional Study.

Second, a survey party composed of the Research Program Coordinator and assistants, would carry out a detailed field inspection of each potential site and the immediate surrounding area. The survey team would compile detailed information with respect to the existence of sites meeting the selection criteria and would note engineering design features, such as terrain slope, drainage, and general soil conditions. Where evident by field inspection, site ownership should be noted. This would likely be possible for public parks, schools, federal agencies, and the like. Ownership of other sites likely will not be obvious by inspection. A photographic record would be desirable. In the heavily urbanized area where appropriate sites may be limited, a systematic street-by-street search may be necessary up to one mile from the analytically defined location. Increased visibility in the rural areas probably will ease the survey procedure appreciably for those areas.

Insofar as possible, on-the-spot assessment of each site should include consideration of the future trends in land usage in the vicinity. Such assessment should focus mainly on the possibility of new construction and related activities in the area which may tend to affect air quality or meteorological measurements of the nearby instruments. Such assessments should be subsequently augmented by consultation with city and county planning commissions, highway departments, and perhaps realty boards.

Third, the potential sites within each area would be ranked with respect to their conformance with the physical selection criteria. Ranking would also acknowledge ownership, where known. Ranking by ownership is of value from the viewpoint of subsequent acquisition tasks and possibly facility operation throughout the course of the Regional Study. That is, it appears most appropriate to limit insofar as possible the number of organizations and individuals with which negotiations are conducted concerning the instrument sites. If, for example, all St. Louis City sites could be selected within city parks, negotiation would be essentially limited to a single group rather than up to perhaps 12 groups in a multiple site ownership site pattern.

Fourth, the ownership, where unknown from the field survey, of the most desirable sites would be determined. Review of land ownership records at the appropriate county offices will reveal this information.

Fifth, zoning regulations and institutional constraints affecting the use of the potential sites should be reviewed. Probably the most important constraint will be associated with the erection of the 30-meter tower within urban areas. Where zoning regulations prohibit such structures, a variance must be sought. Such procedures can be time-consuming and therefore should be initiated at a very early point in the implementation schedule. In certain difficult situations, the use of the more sightly unguyed tower may more easily win a zoning variance. Of course, if these efforts fail, alternative sites must be sought even though they may be less desirable for other reasons.

Sixth, acquisition negotiations with the site owners would be initiated. The nature of the negotiations and the method of acquisition likely will depend largely on the character of the owner. In some cases, site acquisition may be in the form of a no-cost outright loan. In others, however, rental or lease agreements likely will be required. From a point of view of cost, the former method is more desirable but may involve a risk factor of use revocation by the site owner during the Regional Study. Long-term lease avoids this risk. In the event the instrument site is a part of a larger parcel under one ownership, plans for use of the parcel should be reviewed to ensure that the planned use or area stability will not affect the instrument installation.

It should be noted that site selection for the Class C stations will usually be on an ad hoc or perhaps an opportunistic basis determined by the specific research needs fulfilled by the station at the time. Thus, many of the siting criteria would not apply to the Class C stations.